SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

August 10, 2018

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

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

Dear EXCOM Chairs and Members,

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

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

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

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

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

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

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

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

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

  Or

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sincerely,

Bradford W. Parkinson

_____

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

Enclosure: Supporting calculations and graphs

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

Analysis of Ligado May 2018 Proposal and Assessment August 2018

PNTAB

Bottom Line Up Front

- The PNTAB strongly recommends <u>disapproval</u> of Ligado's amended proposal for ~10 watt transmitters of May 31, 2018

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Summary of the latest Ligado Proposal:

1. Completely abandons terrestrial use of the 1545-55 MHz band
2. Reduces Power from 1.5kW to ~10 Watts in 1526-36 MHz band
3. ***Unspecified distance between Transmitters***
4. Monitoring up to users, who must use a call-in number
5. Proposal asserts that it resolves all aviation issues (Aviation community filings disputes this)
6. ***Does not directly address most sensitive receivers – High Performance - but say "Ligado's co-existence agreements with major GPS manufacturers and thousands of hours of empirical testing assure protection for all other classes of GPS devices". Note: High-Performance receivers create over $30B per year in identified benefits to the US.***
   - ***Ligado statement is not true. Top three manufacturers support international standard of 1 dB degradation, equivalent to a 25% drop in GPS signal power.***
   - ***"New" Ligado 10W proposal violates noise standard by factors of 2500 or more at 400m spacing.***
7. Proof of "assured protection" ascribed to Ligado-sponsored tests that were found inadequate & incomplete by independent review board. So "proof" is an erroneous statement.
8. Completely ignores ABC testing for most categories of receivers, which clearly shows proposal is unacceptable.
9. Continues to totally ignore effects on new GPS signals (L1C) and complementary GNSS systems (e.g. Galileo)
10. Military receiver impacts – i.e. M-code must be discussed by USAF who apparently oppose the proposal

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Adjacent band interference concern

"Upper" band is apparently off the table. Is this forever?

"Lower" band Power reduced to ~10 Watts. Spacing not specified but original was ~400 meters. To meet broadband requirements it is possible that this will be less. Perhaps about 100 to 200 meters. Plausibly, perhaps Micro or Femtocells. Microcells typically are a watt at 500 Meters coverage (~1 km spacing). Femto cells are 100 milliwatts at 30 Meters.

Summary Rationale for Disapproval

- PNTAB believes use of GPS should be protected everywhere and for all current and future uses as directed by EXCOM letter in 2011. The "G" in "GPS" should really be Global.
- At "new" ~10 watt power, **tower spacing would have to be *at least 20.4 kilometers* to protect High Performance Receivers, even if only protected over** 90% of coverage area
- Viewed another way, with 400 meter spacing, Ligado power would have to be further reduced from ~10 watts to **0.0036 watts (2500 times lower) to protect tested High Performance Receivers, even if only protected over** 90% of coverage area.
- Asking the High Performance GPS Users to monitor the interference is totally unrealistic – they would not know how to do it, and would have no means to trace the problem to Ligado.
- Ligado continues to ignore emerging use of modernized GPS and GNSS signals. Impacts to receivers tracking these wider bandwidth signals could be worse than for current GPS signals
- If Ligado's current license is approved, their spokesperson implied that over time they would expect to be allowed power increases. Temporary power reductions offered only to gain regulatory approval must be recognized as such and rejected.
- Proposal is deliberately vague on geometry and spacing of towers. Ligado has repeatedly declined to provide these critical technical details to PNTAB to enable full and accurate assessment of interference. They have addressed Aviation (433m) and ignored High Performance Uses that have been shown to be much more sensitive to degradation.

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The Evidence

- **Definition -Degradation Radius** is the distance from the transmitter, beyond which the international ***interference standard*** is not violated.
- That ***standard*** (1 dB degradation) is ***equivalent to a 25% drop in GPS signal power***
  Conceptually, the radius defines ***a circle of degradation.***

- All major GPS manufacturers, the US Air Force, DOT, the Aircraft Industry and many others strongly support this International standard.
- The DOT ABC report performed a detailed analysis in Appendix I. These scientific results form the basis for our analysis

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Overview: Transmitter Power, Transmitter **Tower Spacing** and **Percentage Degradation Area** for GPS receivers

- Virtually all receivers will be degraded if they are too close to a Ligado Transmitter (overwhelm the "front-end")
- Consider a ***hypothetical case,*** where receivers can be degraded up to **10% of their operating area**
  - Then **degradation radius** around each tower must be ***less than 0.17 times the spacing*** ***This is called the Degradation Limit Radius***
  - This can be achieved by either **reducing power** or **increasing spacing** (decreasing tower density)
- Earlier Ligado proposal is that tower spacing should be ~400 meters.

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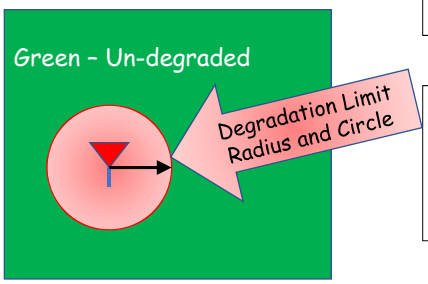
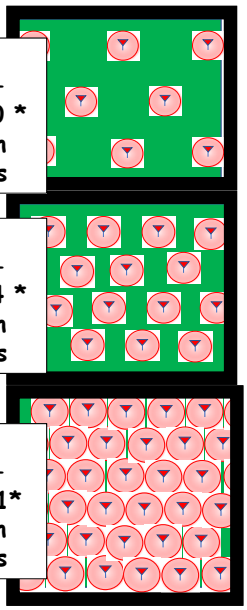
A visual Example:
To insure additional interference noise does not exceed 25% International Standard either:

- **Limit closest Transmitter Spacing** for a given power
  Or
- **Constrain Power** for a given spacing (Reduce Degradation Radius)





90% Area Protected – spacing = 6.0 * Degradation Limit Radius

50% Area Protected – spacing = 2.4 * Degradation Limit Radius

20% Area Protected – spacing = 2.1* Degradation Limit Radius

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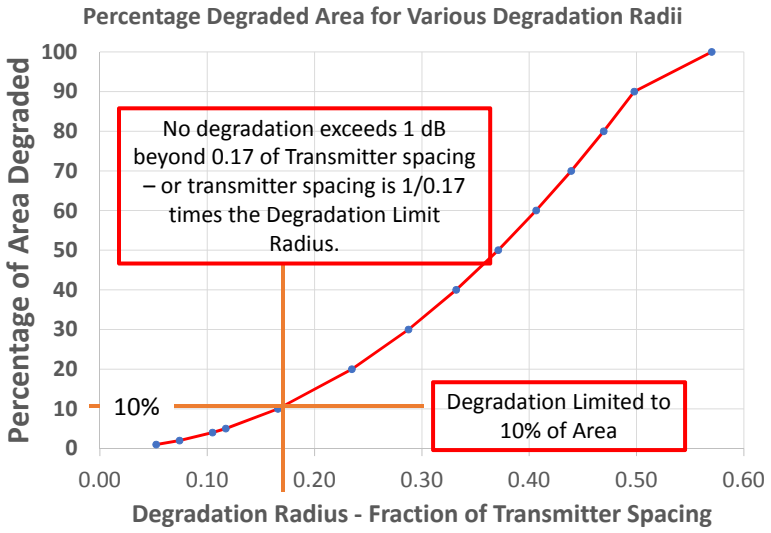
Tradeoff – Degradation Radius versus % of Region Degraded –
Relationship defined by simple, directly-scalable geometry…



Reminder: the only tests that met the PNTAB criteria were the DOT's Adjacent Band Compatibility

COMPLIANCE WITH PNTAB CRITERIA

PNTAB Evaluation Criteria	TWG	NPEF Rounds 1 & 2	RAA	NASCTN	DOT
1. Used 1 dB IPC as metric	●	●	○	○	●
2. Included all classes of receivers	●	○	○	○	●
3. Included all modes of operation	●	●	○	●	●
4. Focused on stressed conditions	●	●	○	●	●
5. Addressed impact on emerging GNSS	○	○	○	◑	●
6. Included GNSS experts and public	●	●	○	◑	●

Figure 1. Summary of PNTAB Criteria Evaluations

Ligado Sponsored

"ABC"

Key:
Fully Compliant ●
Non-Compliant ○

JAMES R. HOREJSI, GG-15
DOD NPEF Co-Chair

KENNETH K. ALEXANDER
DOT NPEF Co-Chair

Example of ABC Test Results: Interference "Masks"

(Tolerable Received Power from Adjacent Band –all receivers in each class)

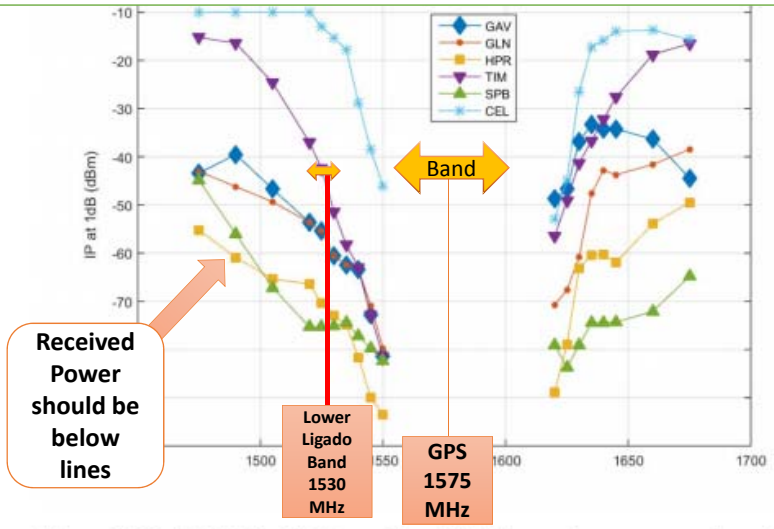
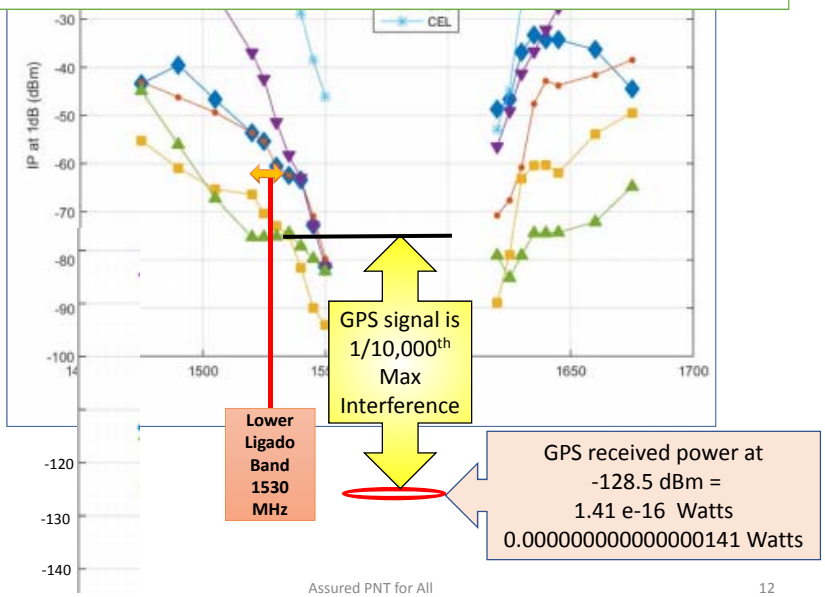


Figure 3-22: GPS L1 C/A bounding ITM for each category of receivers

On the same Scale – Received *GPS power* is less than 1/10000th of the Adjacent band degradation power. That is the reason GPS is located next to the MSS band



Determining Allowable *Transmitter power* from ABC measured acceptable *GPS Receiver degradation*

- The DOT also performed a detailed analysis of ***transmitter antenna patterns and transmitter power levels*** around the proposed transmitters.
- They used the measured receiver Interference Masks to calculate allowable transmit power at various ranges from the Ligado Transmitters
- Considered Classes of receivers (80 were tested):
  - High Precision and Networks (HPR)
  - General Aviation and Helicopters (non-certified) (GAV)
  - General Location/Navigation including emergency response vehicles (GLN)
  - Timing (TIM)
  - Celluar (CEL)

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From Appendix I -DOT Test and Analysis:
High Performance Receivers –
Impacts of ***single 10W Ligado micro-Urban*** transmitter.
* **Degradation Radius is 3.4 Km.**
* Start loosing Low Elevation Satellites at 560m.
Start Loosing All Satellites at 170m

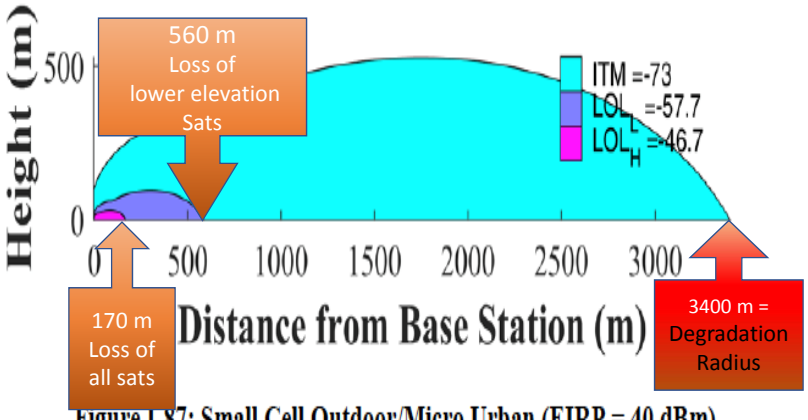

Figure I-87: Small Cell Outdoor/Micro Urban (EIRP = 40 dBm), Bounding HPR, 1530 MHz

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Hypothetical Tower Spacing Example for High Performance Receivers

- Assumptions:
  - Ligado Power of 10 Watts
  - *Hypothetical* protection of only 90% of transmitter region
- What is the closest spacing that would insure GPS protection from 25% noise increase?
  - Answer: 6.0 times the degradation radius. *Previous example showed a 3400 Meter Degradation Radius from ABC Report Appendix I*
- Therefore: Protection of High Performance Receivers would require tower spacing of 20.5 km (12.7 miles), even if protected over only 90% of the cell area

10 watt transmitters clearly incompatible with use of High Precision Receivers
(in fact All of Region is degraded at spacing of 5 km)

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

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

We strongly believe 90% is the minimum Area Protection Criterion (maximum 10% degradation)

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For closer spacing - Maximum allowable Ligado Power to insure:
***GPS** Protection for 90% of Transmitter Region .*

High Performance Receivers Protected	Tower Spacing			
	1000 Meters	400 meters	200 meters	100 meters
All	.023 W	.0036 W	.00089 W	.00022 W

Based on envelope of quantitative data taken from 40 Different HPRs, tested by DOT for Adjacent Band Compatibility

It may be worse – *not included in analysis*…

- **Multiple towers** contribute additive noise
- **Reflections** from ground and buildings can increase normal $1/R^2$ models by factors of over 10 (Factors of 15 measured in Las Vegas tests)
- The **newer GNSS signals** have wider RF bandwidths for greater accuracy and A/J, but the receivers also may have greater sensitivity to the adjacent band power. In ABC tests, the Galileo E1 signal *was more sensitive* for HPRs.
- The **new military signal** deliberately pushes energy away from the center frequency, closer to Ligado power.

Clash – *Fundamental Incompatibility*

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

DOT Adjacent Band Compatibility Tests – 90% Protection Evaluation

Deployment	Stand off distance (m)	Max Tolerable EIRP			
		GLN	HPR	TIM	CEL
Macro Urban	10	0.8 mW	64 μW	8.7 mW	12.3 W
	100	79.4 mW	6.5 mW	0.9 W	1.26 kW

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PNTAB Recommendations

- Strongly recommend rejecting latest Ligado 10 watt proposal
  - Does not meet PNT EXCOM January 2012 goal to protect "existing and evolving uses of space-based PNT services"
  - Not even close
- Apply DOT Adjacent Band Compatibility (ABC) results and methodology to any future proposals

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Backups

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Instead of constraining Minimum transmitter separation, consider Constraining the Ligado Transmitter Power
and
Still meeting the 90% Area Degradation Criterion

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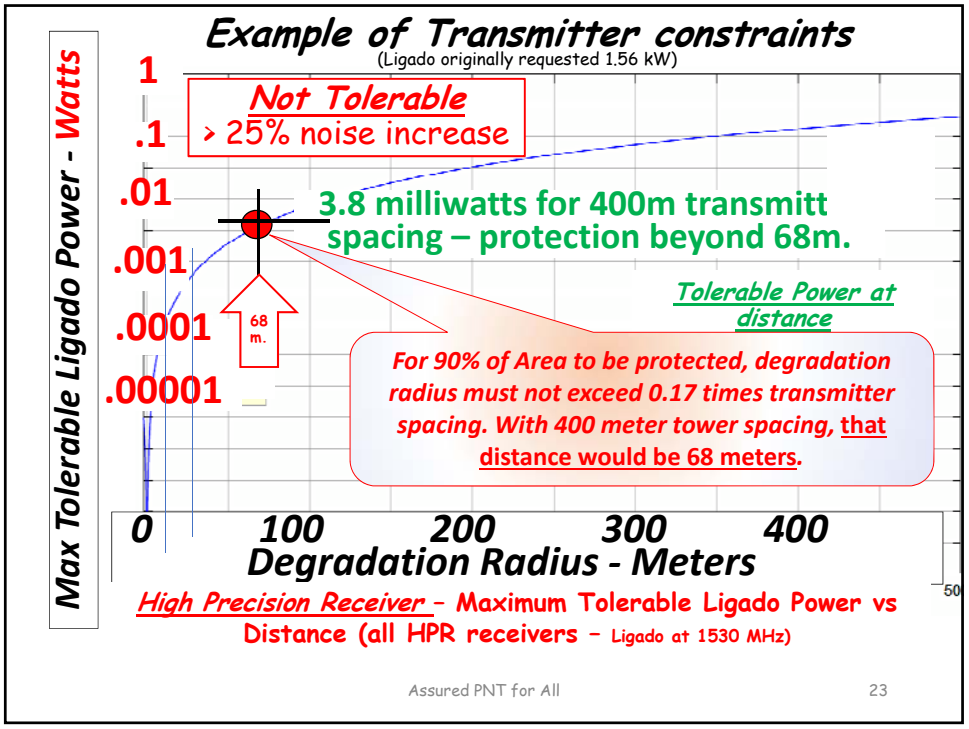
Example of Transmitter constraints
(Ligado originally requested 1.56 kW)
Max Tolerable Ligado Power - Watts
1
.1
.01
.001
.0001
.00001
Not Tolerable
> 25% noise increase
3.8 milliwatts for 400m transmitt spacing – protection beyond 68m.
68 m.
Tolerable Power at distance
For 90% of Area to be protected, degradation radius must not exceed 0.17 times transmitter spacing. With 400 meter tower spacing, that distance would be 68 meters.
0
100
200
300
400
Degradation Radius - Meters
High Precision Receiver – Maximum Tolerable Ligado Power vs Distance (all HPR receivers – Ligado at 1530 MHz)
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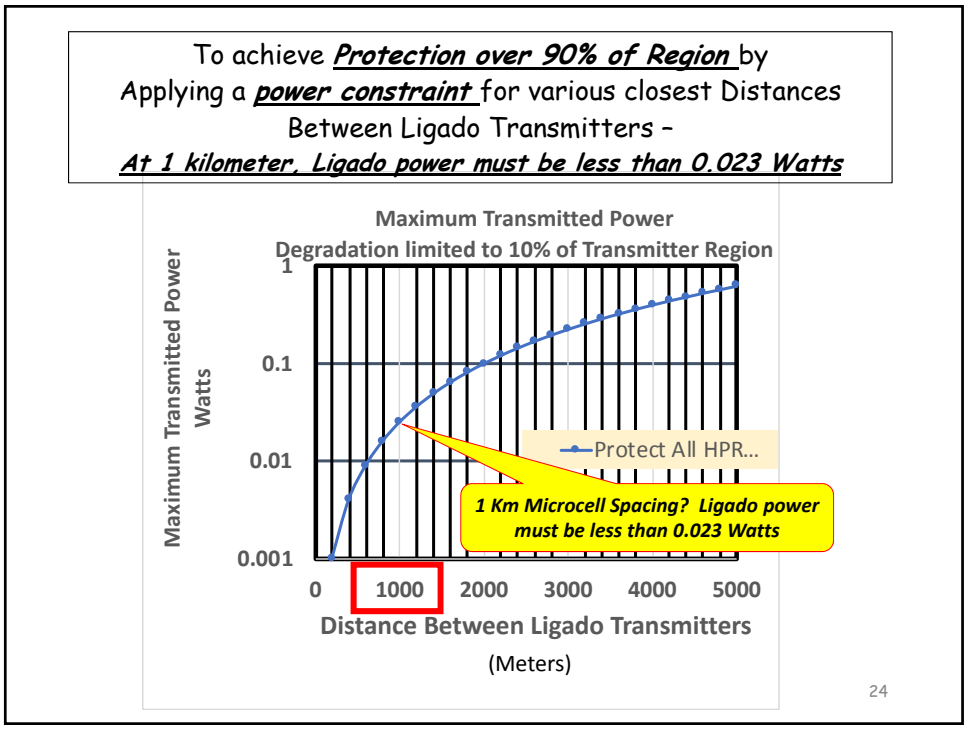
To achieve Protection over 90% of Region by Applying a power constraint for various closest Distances Between Ligado Transmitters –
At 1 kilometer, Ligado power must be less than 0.023 Watts
Maximum Transmitted Power
Degradation limited to 10% of Transmitter Region
Maximum Transmitted Power Watts
1
0.1
0.01
0.001
Protect All HPR...
1 Km Microcell Spacing? Ligado power must be less than 0.023 Watts
0
1000
2000
3000
4000
5000
Distance Between Ligado Transmitters
(Meters)
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Three Levels of Adjacent Band Interference - ABI

Already Presented

1. **Increase of noise floor by >25%** (the "1dB" criterion). We have used this level to define the "*Degradation Radius*"

But there are two more serious levels:

2. **Onset of *total loss of Low Elevation* Satellites** – the "*Loss of Low Elevation*" radius.
3. **Onset of *total loss of all* satellite signals** – the "*Total Loss*" radius

The calculation of % of regional area with a particular ABI effect proceeds in the same way as the 25% degradation (#1)

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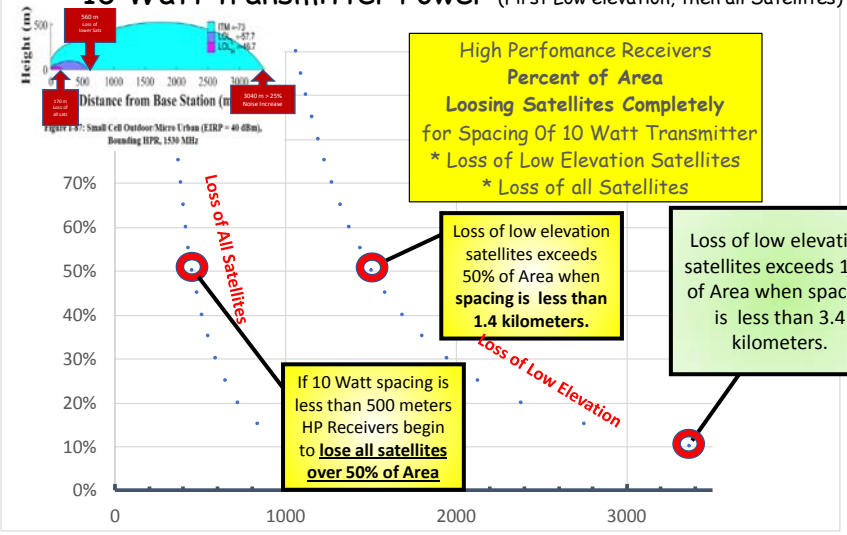
High Performance Receiver Loss of GPS signal

10 Watt transmitter Power (First Low elevation, then all Satellites)



Transmitter separation – Meters

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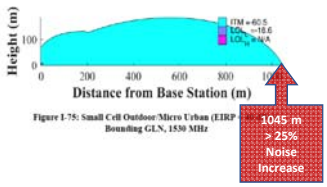
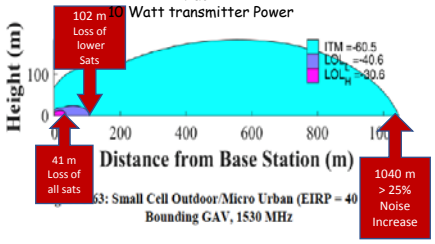
Analysis for all three levels of Interference was performed by DOT - Examples for various classes of GPS Receivers follow

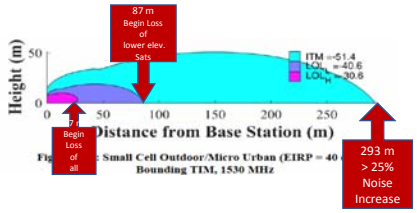
Emergency Services and General Navigation Receiver Degradation Radii
10 Watt transmitter Power



Helicopter and General Aviation Receiver Degradation Radii
10 Watt transmitter Power



Timing Receiver Degradation Radii
10 Watt transmitter Power



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Q. What should the degradation radius be, such that no more than 10% of a given region is degraded?

A. It scales directly with the separation distance and, for 10% regional degradation, is 0.17 times that separation.

(At 0.57 times separation, 100% is degraded)

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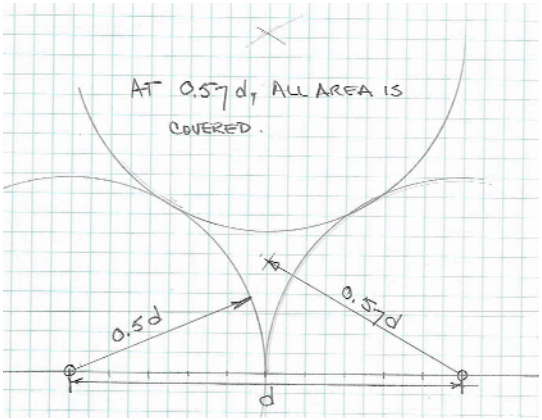
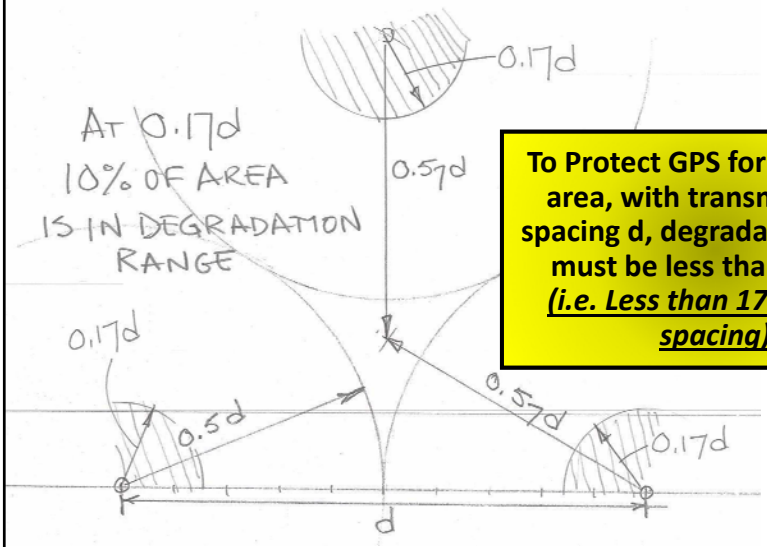
Max Ligado Transmitter Power and tower density should be constrained by the % area that is degraded



Geometric problem directly scales with spacing of transmitters (d)
Furthest point from all is at $1/3^{0.5}$ times d = 0.57 * d

For Example:
At 0.57 *d, 100% of the area would be covered

What degradation radius would result, if degradation were limited to 10% of the area?



To Protect GPS for 90% of an area, with transmitters at spacing d, degradation radius must be less than 0.17 d. ***(i.e. Less than 17 % of the spacing)***

Whatever the Ligado spacing, to protect 90% of the Region, the degradation radius must not exceed 17% of the Spacing between Transmitters

Results for other classes of receivers – Maximum Tolerable Power at certain sizes of Degradation Circle

From DOT Adjacent Band Compatibility Tests

Deployment	Degradation Circle Radius	Max Tolerable EIRP			
		GLN	HPR	TIM	CEL
Micro Urban	10	1 mW	76 μW	9.8 mW	11.7 W
	100	104 mW	7.8 mW	1 W	1.2 kW

In fact, using the ABC results and the proposed 10 Watt Ligado transmissions, **50 % of the 40 tested HPR receivers would be degraded beyond the 10% degradation circle at a transmitter spacing of 280 Meters**

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