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Analysis of Ligado May 2018 Proposal and Assessment August 2018

PNTAB Draft

Bottom Line Up Front

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

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

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.

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

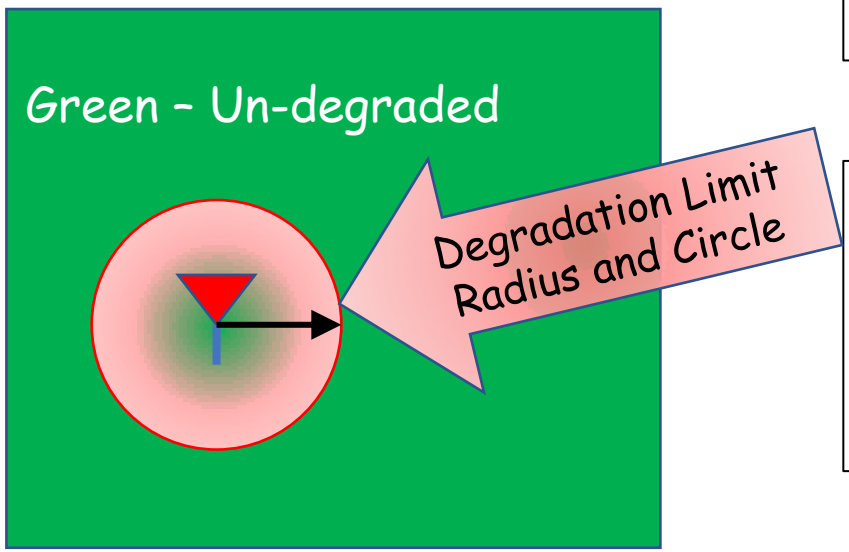
Overview: **Transmitter Power**, Transmitter **Tower Spacing** and **Percentage Degradation Area** for GPS receivers

- 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.

A visual Example:

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

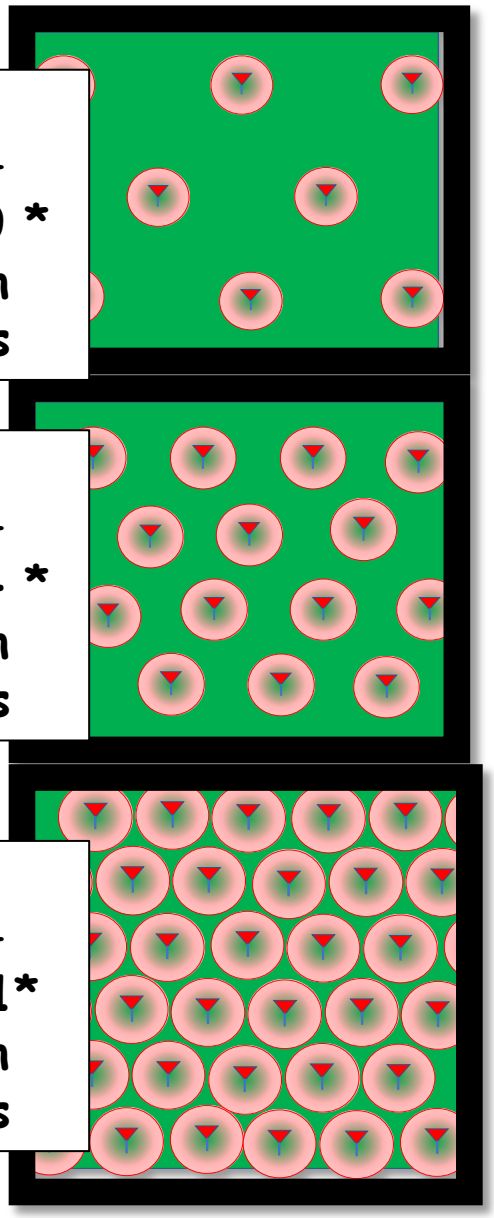
- **Limit closest Transmitter Spacing** for a given power
  Or
- **Constrain Power** for a given spacing (Reduce Degradation Radius)



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

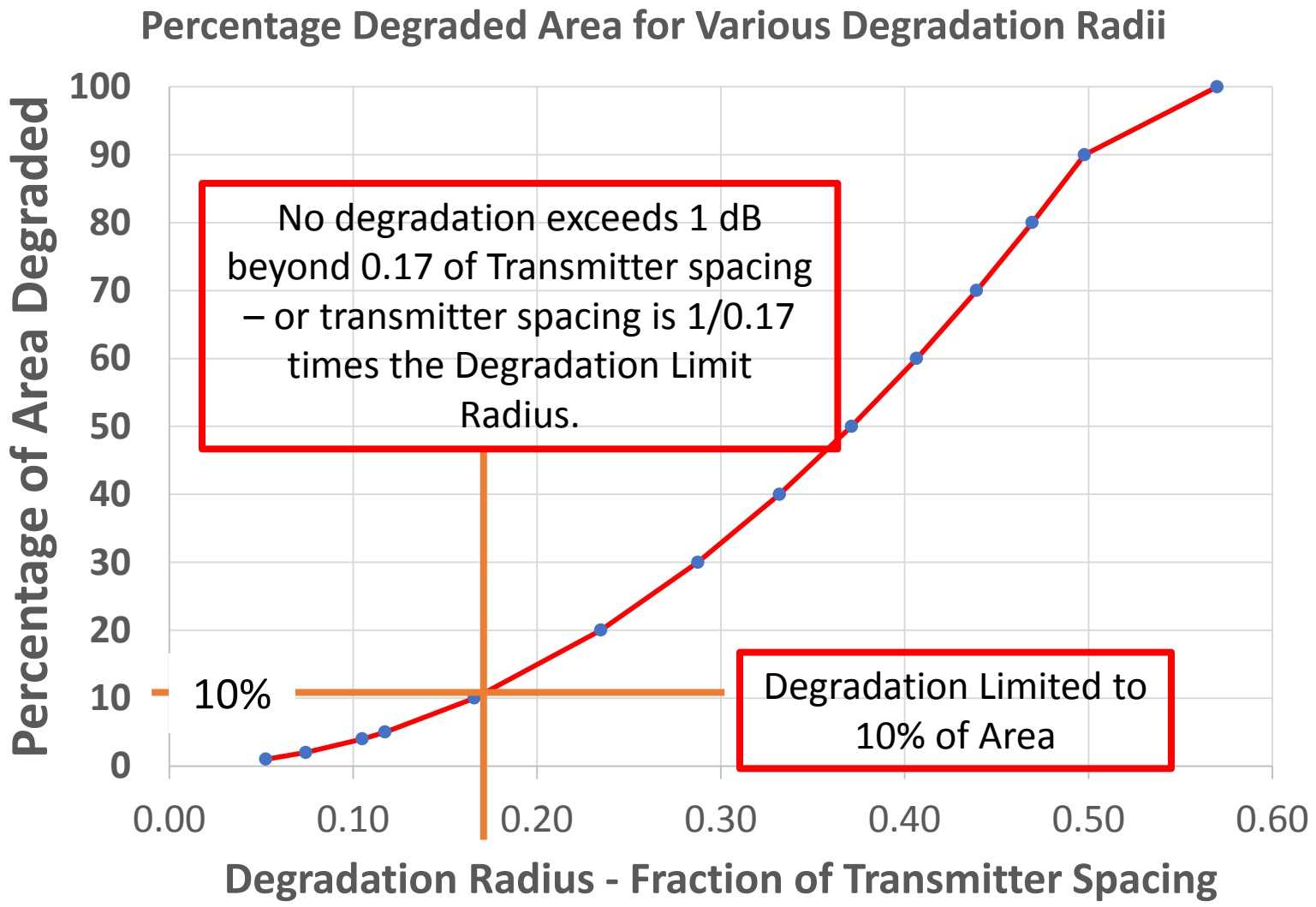
50% Area Protected – spacing = 2.4 * Degradation Limit Radius

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



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 ○

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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)

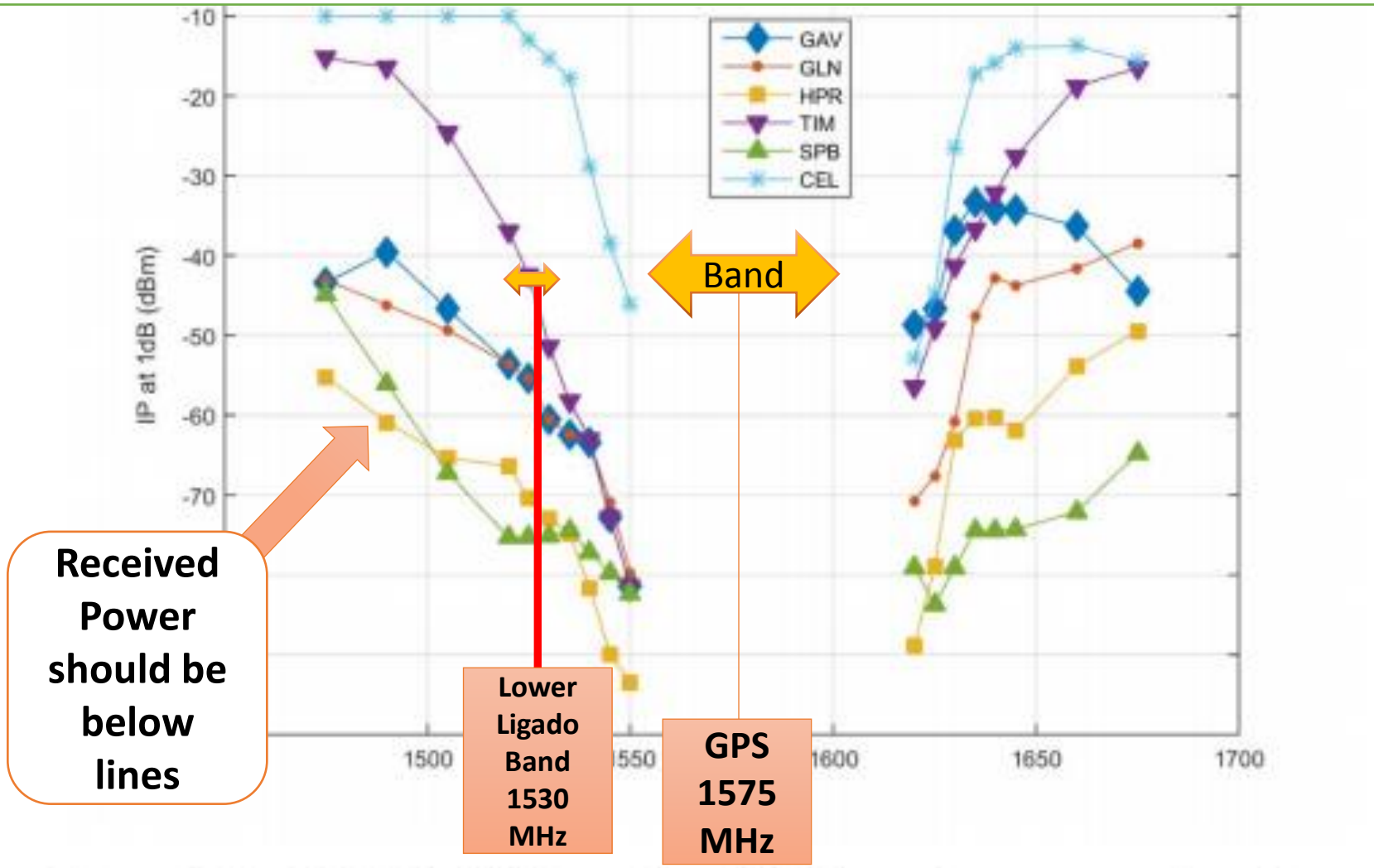
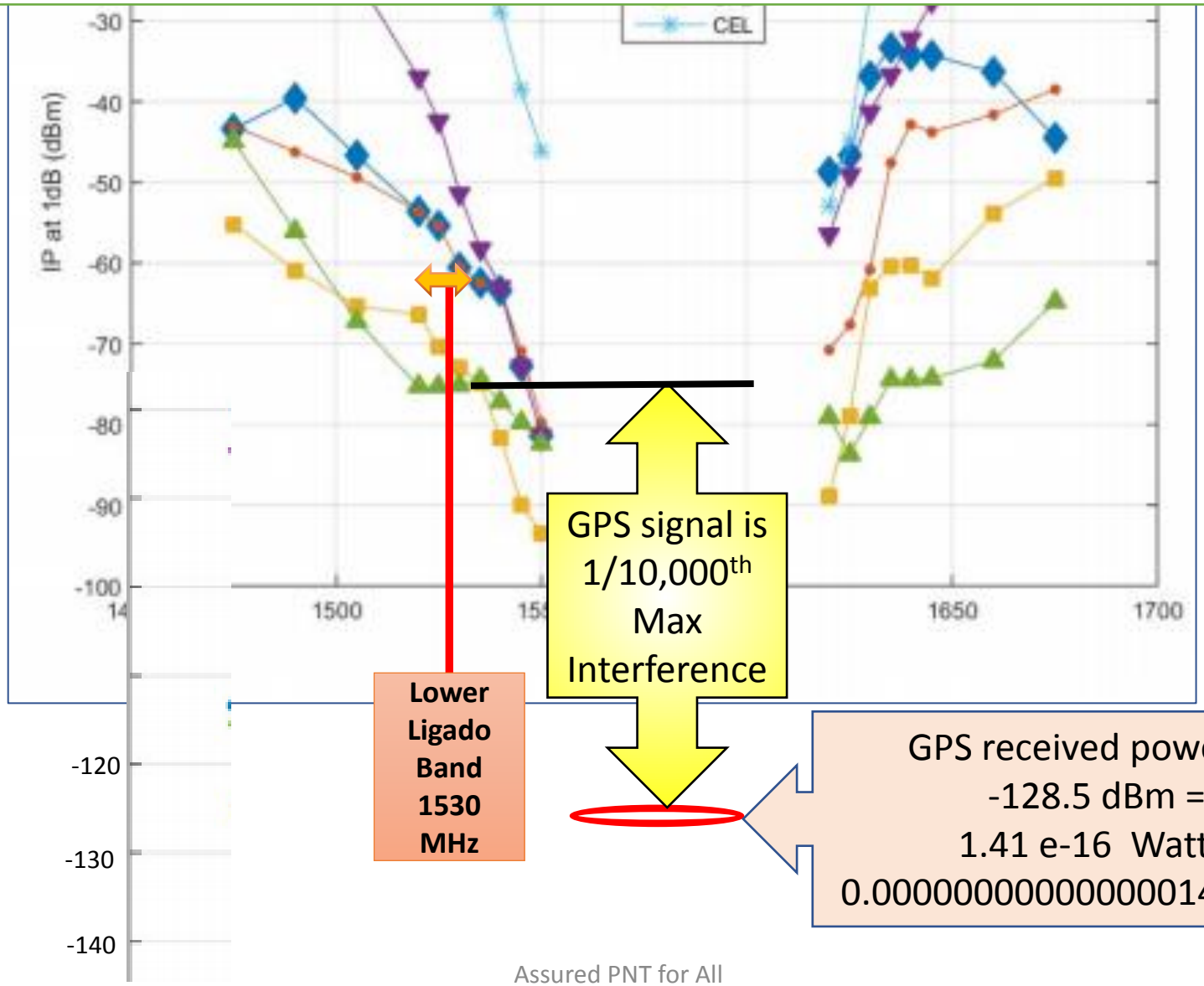


Figure 3-22: GPS L1 C/A bounding ITM for each category of receivers

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)

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

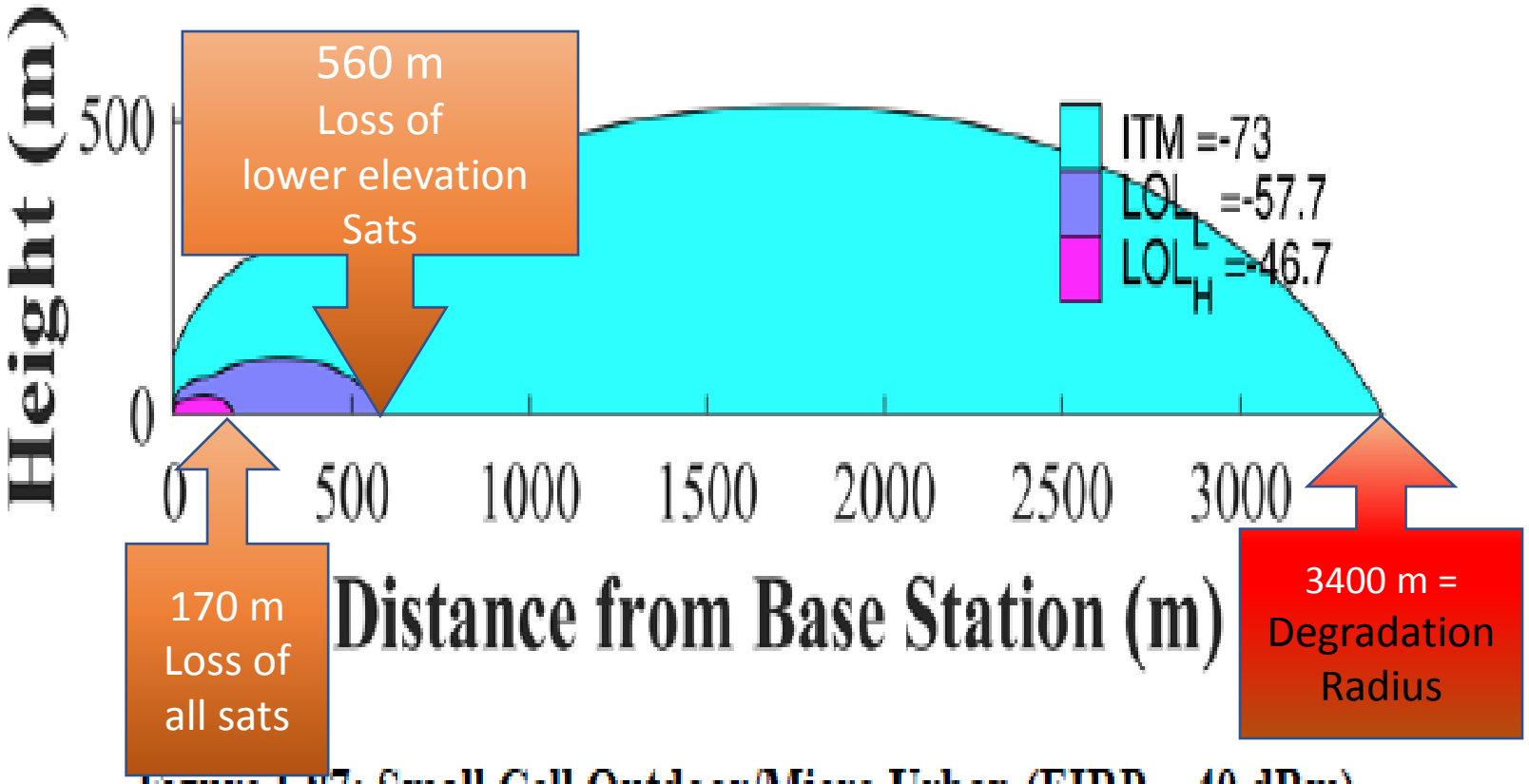


Figure I-87: Small Cell Outdoor/Micro Urban (EIRP = 40 dBm), Bounding HPR, 1530 MHz

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)

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)

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

PNTAB Recommendations

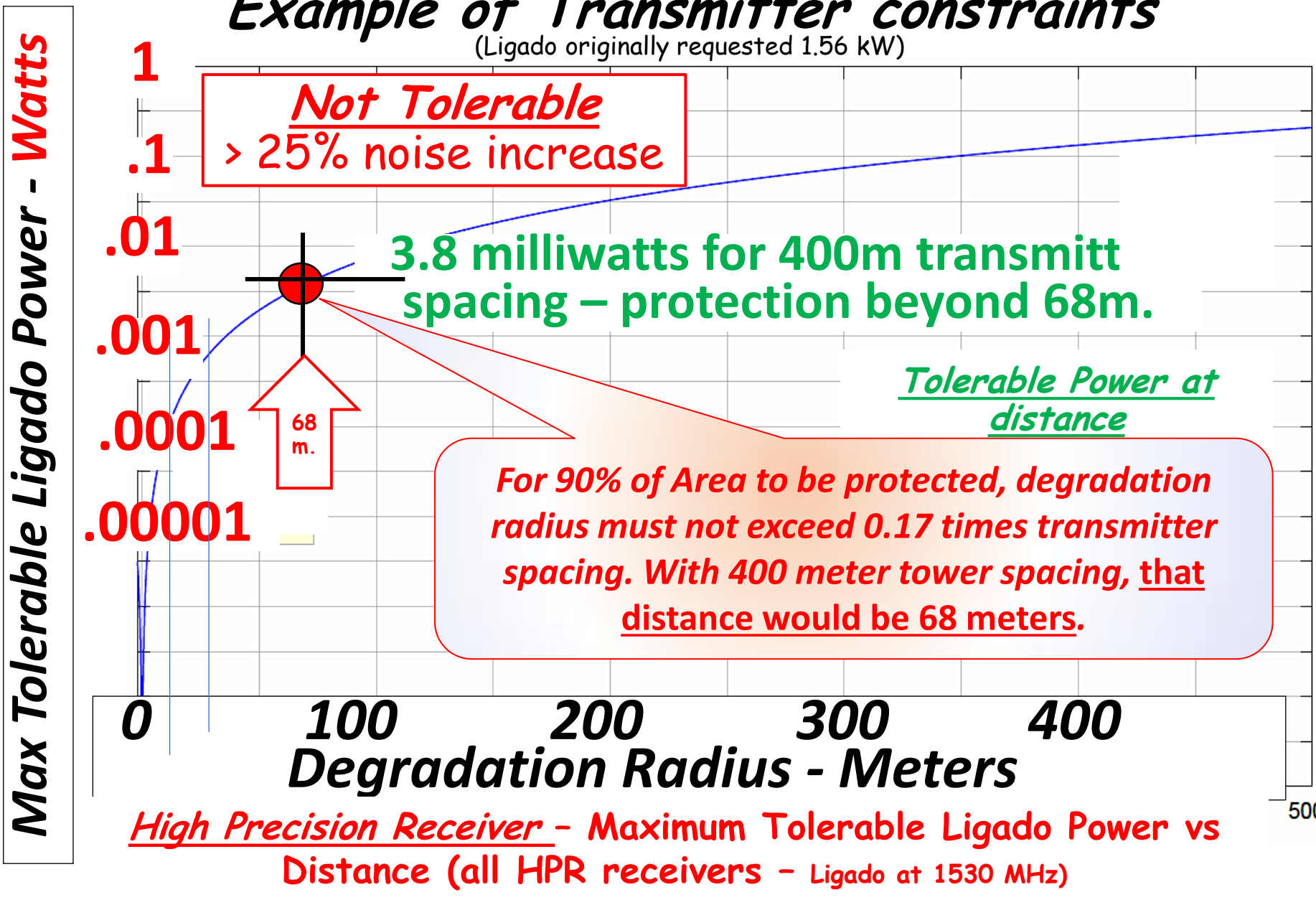
- Strongly recommend rejecting latest Ligado 10 watt proposal
  - Does not meet PNT EXCOM January 2012 goal to protect "existing and evolving uses of space-based PNT services"
  - Not even close
- Apply DOT Adjacent Band Compatibility (ABC) results and methodology to any future proposals

Backups

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

Example of Transmitter constraints

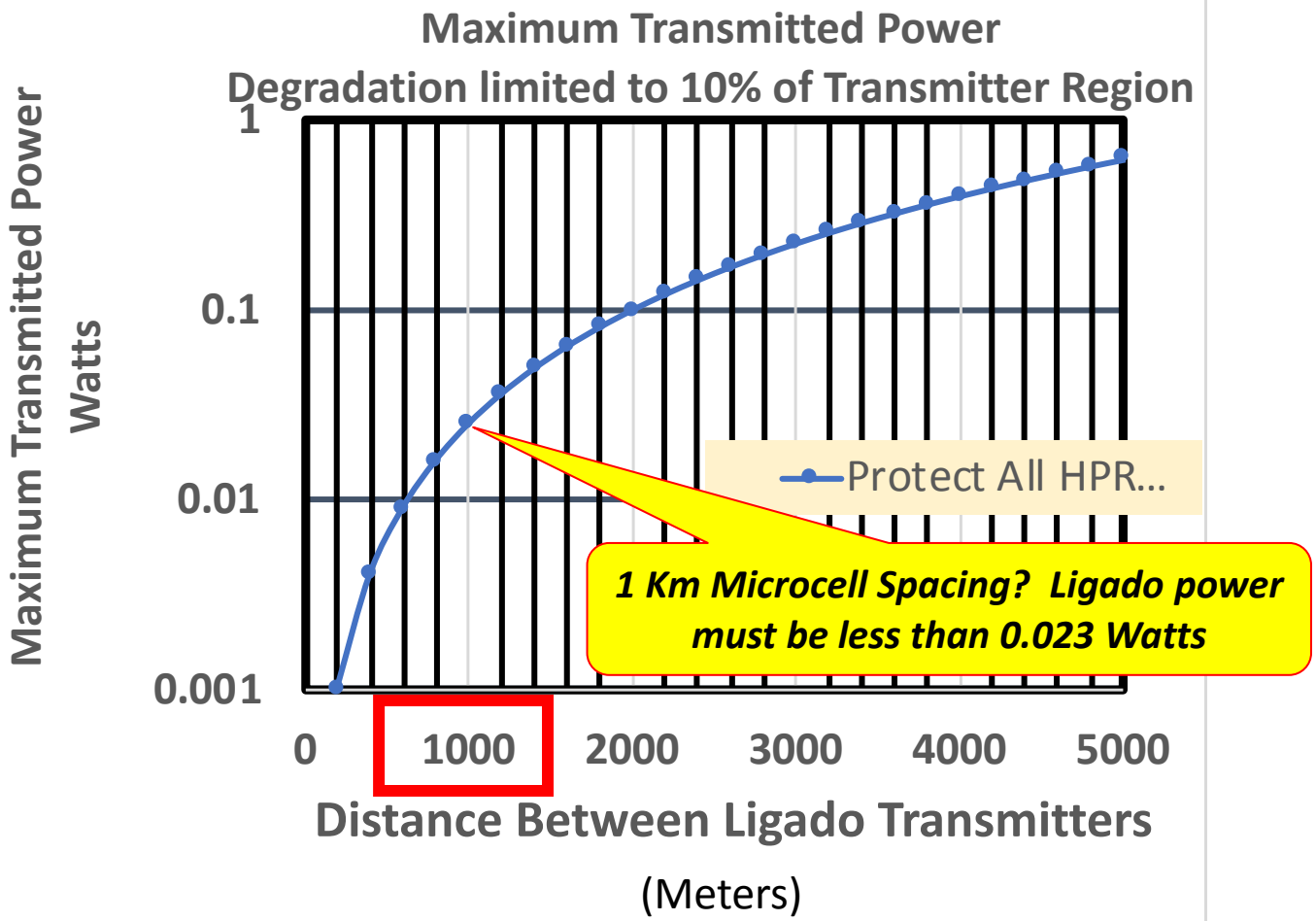
(Ligado originally requested 1.56 kW)



High Precision Receiver – Maximum Tolerable Ligado Power vs Distance (all HPR receivers – Ligado at 1530 MHz)

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



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)

High Performance Receiver Loss of GPS signal

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

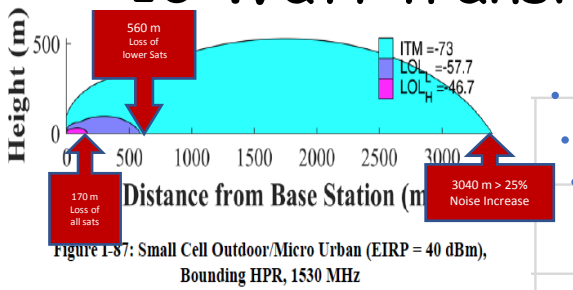


Figure 1-87: Small Cell Outdoor/Micro Urban (EIRP = 40 dBm), Bounding HPR, 1530 MHz

High Perfomance Receivers
Percent of Area
Loosing Satellites Completely
for Spacing Of 10 Watt Transmitter
* Loss of Low Elevation Satellites
* Loss of all Satellites

70%
60%
50%
40%
30%
20%
10%
0%
0
1000
2000
3000

Loss of All Satellites

Loss of Low Elevation

Loss of low elevation satellites exceeds 50% of Area when **spacing is less than 1.4 kilometers.**

Loss of low elevation satellites exceeds 10% of Area when spacing is less than 3.4 kilometers.

If 10 Watt spacing is less than 500 meters HP Receivers begin to **lose all satellites over 50% of Area**

Transmitter separation – Meters

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

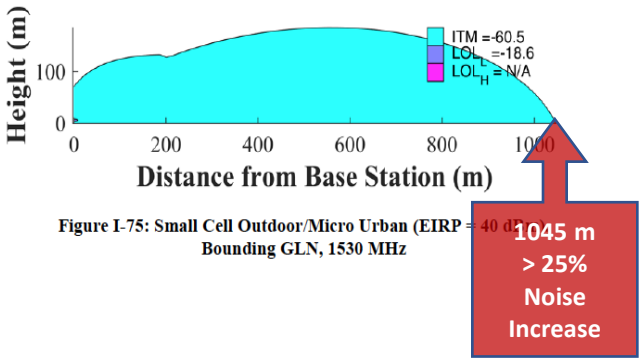
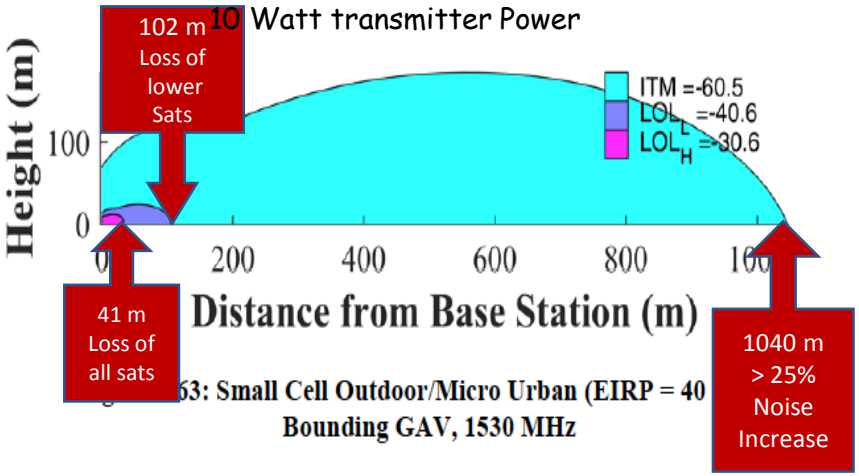


Figure I-75: Small Cell Outdoor/Micro Urban (EIRP = 40 dB
Bounding GLN, 1530 MHz

Helicopter and General Aviation Receiver Degradation Radii
10 Watt transmitter Power



63: Small Cell Outdoor/Micro Urban (EIRP = 40
Bounding GAV, 1530 MHz

Timing Receiver Degradation Radii
10 Watt transmitter Power

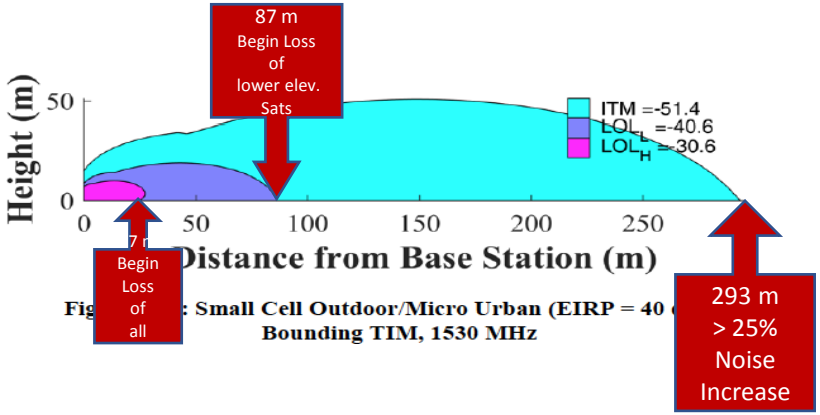


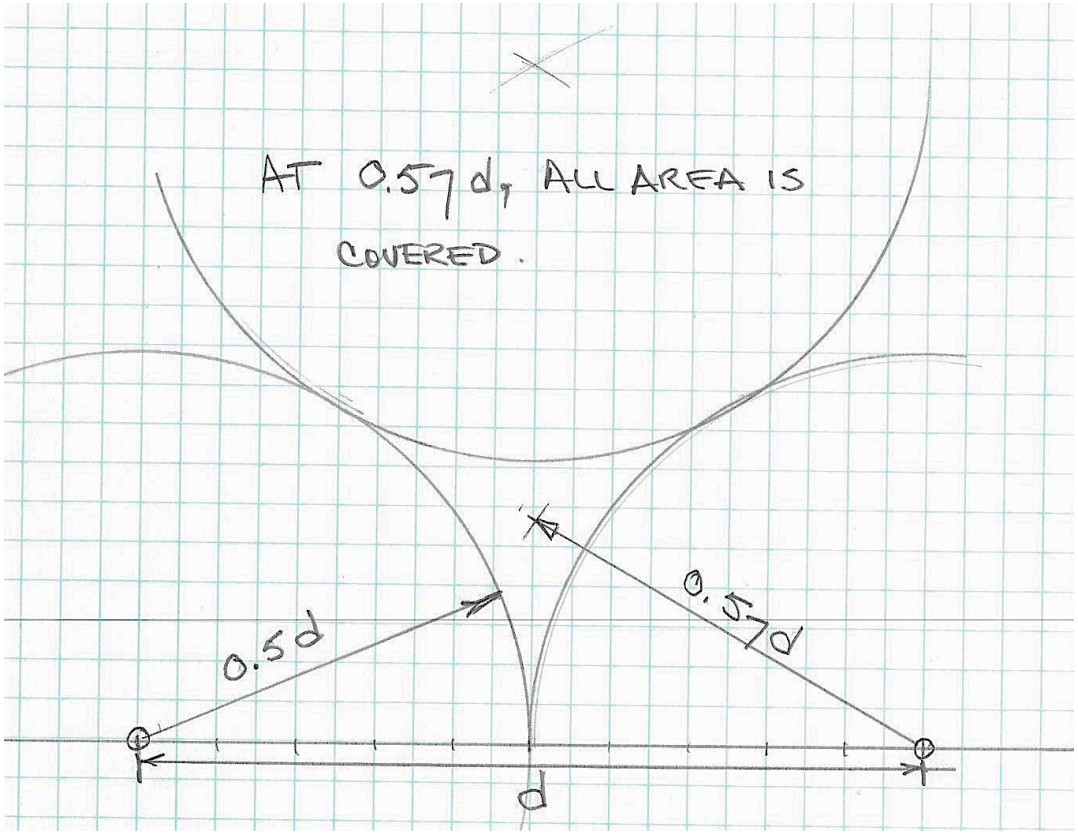
Fig : Small Cell Outdoor/Micro Urban (EIRP = 40
Bounding TIM, 1530 MHz

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)

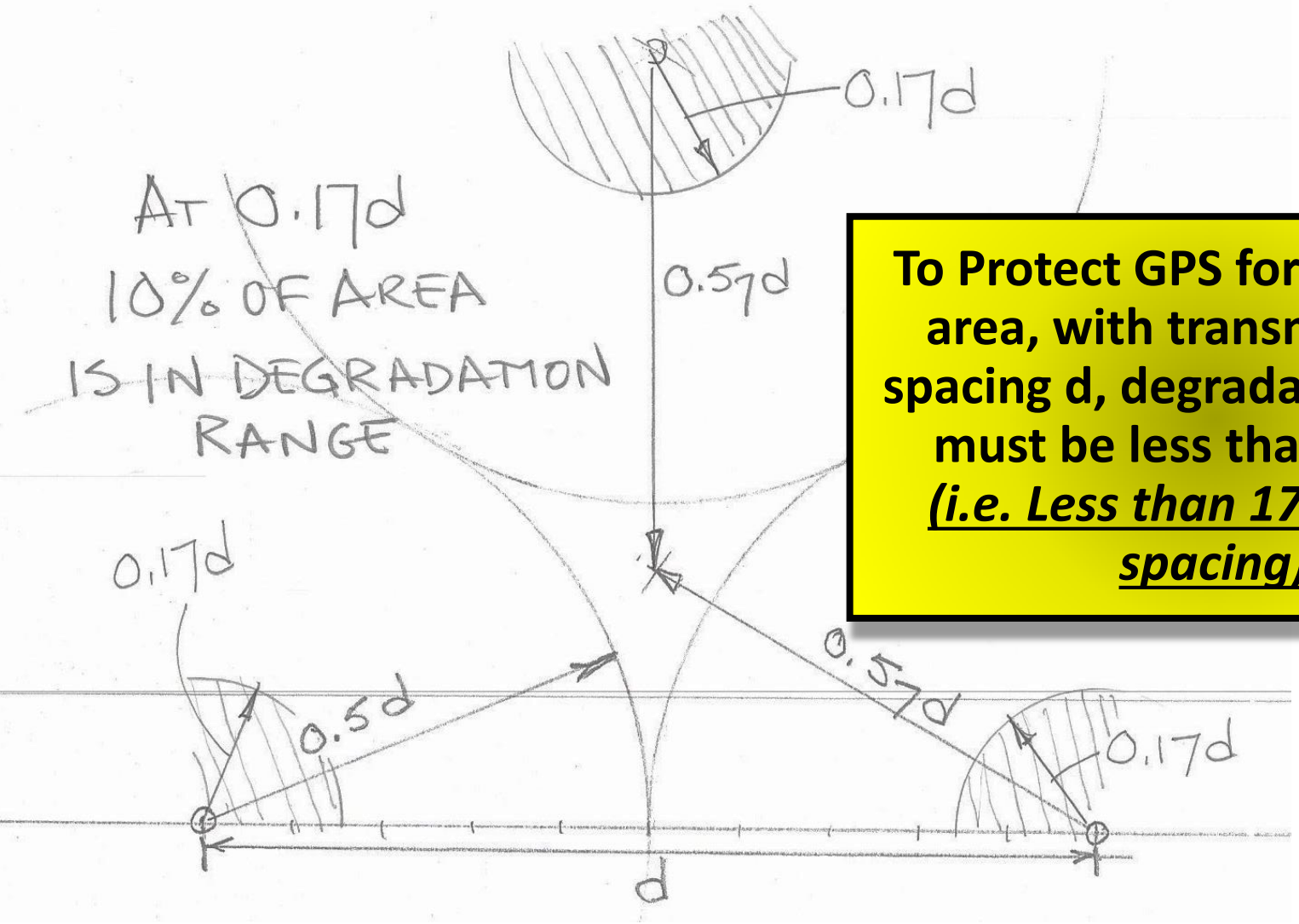
Max Ligado Transmitter Power and tower density should be constrained by the % area that is degraded



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**