

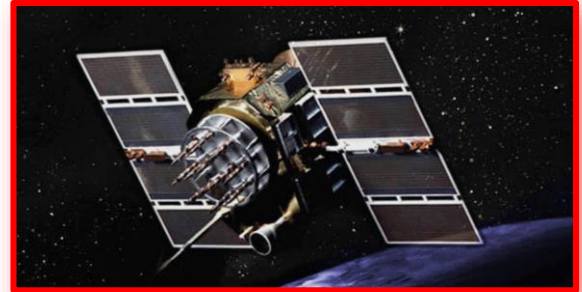
Summary for New Members and Update: A Grave threat to GPS -

for many users: FAA, DOT, NASA
and
other High-Precision Applications

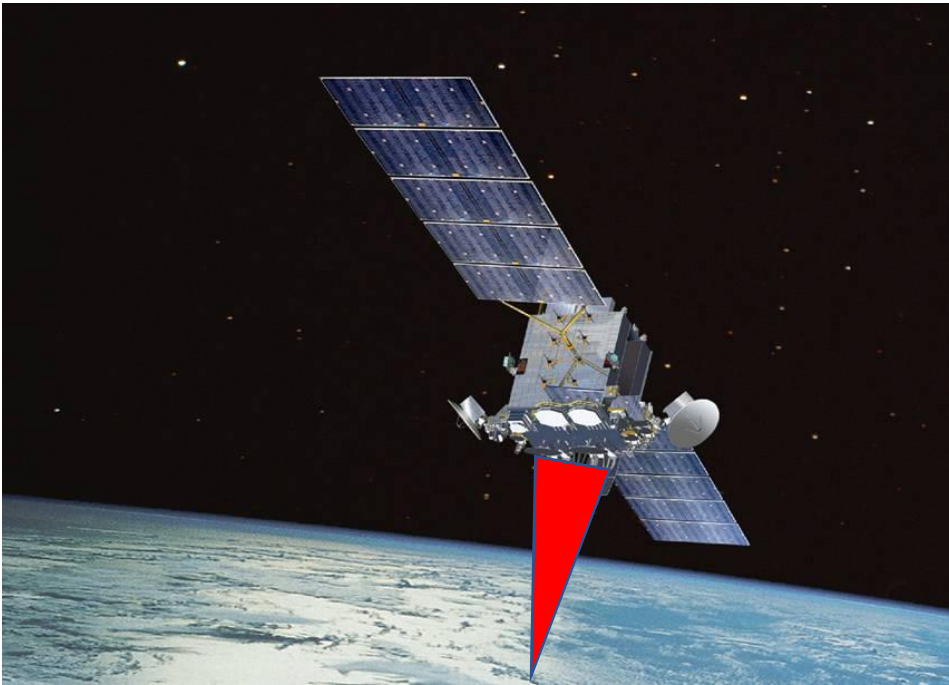
Brad Parkinson Stanford

GPS - 24/7, worldwide

(Accuracies to fractions of an inch)



- Received signal weaker than a millionth of a billionth of a watt
- Over 3 Billion receivers in Use across planet
- Taken for granted world wide - literally 100s of applications
- Economic value greatly exceeds \$65B/year
- An essential part of US infrastructure (DHS)



Background:

A subject that has occupied us for over 8 years

- A certain company (Ligado) has License for transmitting Satellite to Ground for Communications in the very quiet MSS Band - very close to the Main GPS frequency
- *But the received terrestrial power is very low and does not support a large Data Rate*
(and did not interfere with GPS!)

But Ligado saw a great opportunity

- Convert the License to high power terrestrial transmissions (Asked for 15.8 Kw)
 - Said Tower Spacing would be about $\frac{1}{4}$ mile
 - Would support broadband - sending movies etc. = 5G?
 - **Spectrum Value would jump: \$2B → \$12B+**
- Tried to get the FCC to agree just before Thanksgiving 2010 - while most were preoccupied with the holiday
- PNT community found out and realized this would do grave harm to GPS civil receivers- We helped slow the process down. Over \$60B per year in productivity benefits were at risk...
- But*But allegedly a predecessor Lxxx company had already known there was a significant Clash with GPS...
 - According to Harbinger lawsuit now on hold

Adjacent band interference concern

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



“Lower” band terrestrial Power proposal reduced to 9.8 Watts. Spacing not specified but original was ~400 meters. To meet 5G requirements it probably will be less. Perhaps about 100 to 300 meters.

Bottom Lines Up Front

- Ligado recently proposed 9.8 watt transmitters.
 - Unknown, but probably very close tower spacing (100 to 300 meters is typical 5G)
 - Company could receive a windfall profit of over \$10B
- **Even at this reduced power level, Over half the High Precision GPS receivers would be degraded over more than 10% of the operating Region, with many degraded over 100% of the Region**
(Based on DOT extensive ABC Testing)
- Many other organizations have filed opposition
- **The PNTAB has strongly recommended disapproval of this proposal *Nothing has changed - our recommendation still stands***

At Stake: High-Precision = High-Productivity Applications

Partial List - Green particularly at risk

Aviation

- Area and Enroute Navigation

- Approach to Airport
- Landing to Cat III
- NextGen & ADS-B
- UAV Guidance (Drones)

Agriculture

- Auto Farming
- Crop Spraying
- Precision Cultivating
- Yield assessment

Robotics Machinery

- Construction
- Mining
- Geomatics

Science

- Interstellar
- Earth
- Mars
- Earth

- Rotation Rate
- Weather Probes

Summary of Preliminary 2013 US GPS Benefit Estimates		
Application Category	Range of Benefits (\$ billions)	Mid-range Benefits (\$ billions)
Precision Agriculture – grain*	10.0-17.7	13.7
Earthmoving with machine guidance in construction*	2.2-7.7	5.0
Surveying	9.8-13.4	11.6
		0.145
		0.055
		0.185
	7.6-15.3	11.9
		0.038
		0.05
		5.5
	9.8-31.4	20.6
TOTAL (with alternative estimates for timing and consumer LBS averaged)	37.1-74.5	**68.7

Assured PNT for All 3

• Over \$65B In Annual Benefits in identified Commercial Areas

• Hi Productivity >\$33B - Heavy Reliance on High Precision GPS

• Geographic Information Systems (GIS)

High Productivity: In harm's way ... Apt to be much less than 400 meters away from Transmitter

Construction/Infrastructure Scenarios



Photo courtesy of WSP Canada Inc

GPS HPR receiver used in construction/surveying



Photo courtesy of WSP Canada Inc

GPS HPR receiver used in construction/surveying



Photo courtesy ThinkStock

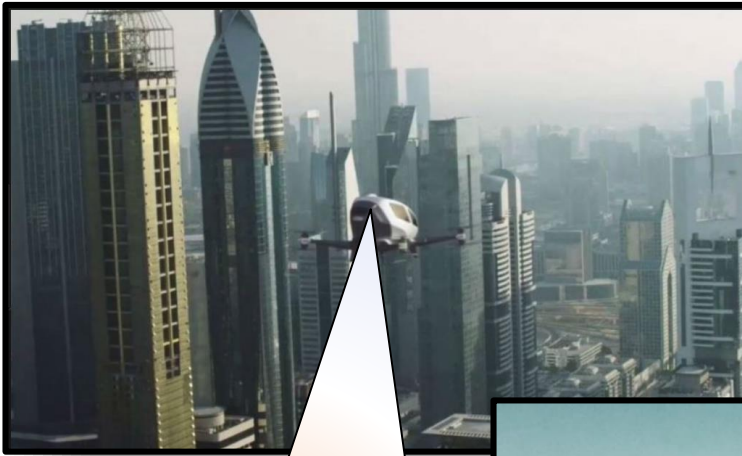
GPS HPR receiver used in construction guidance



Photo courtesy Medvedkov/ThinkStock

Construction/Surveying

Also In Harm's Way: Rapidly growing RPV/UAV applications

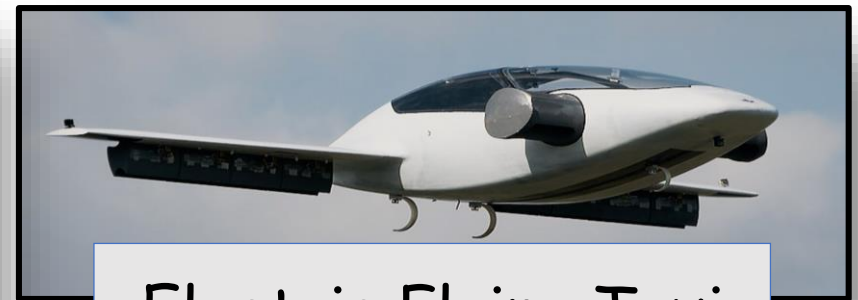


Both RPV Control and Air Traffic Monitoring depend on GPS – probable paths less than 400 Meters to Transmitter sites Apt to be Directly in Main Ligado Beam

Also In Harm's Way: All future Robotic "Air Taxis" Navigation and Air Traffic Monitoring will depend on GPS -Apt to be Directly in Main Ligado Beam



Volocopter



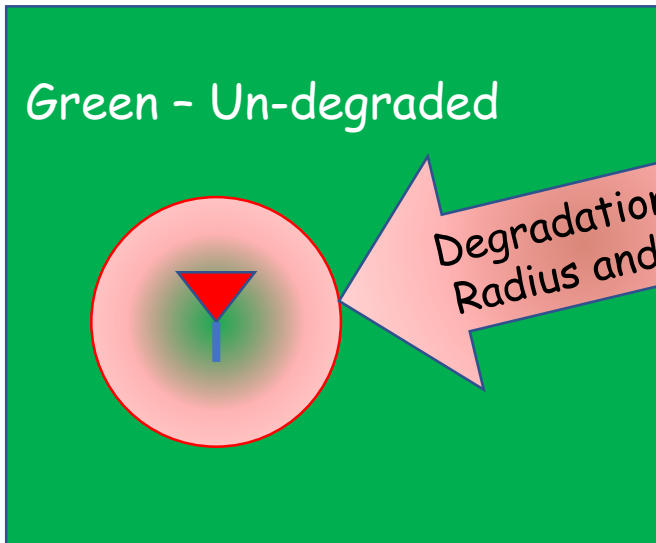
Electric Flying Taxi
by Lilium



Airbus UTM

Outline of Analysis with typical 5G transmitter result included

Extensive DOT GPS testing helped define A "Degradation Radius"



- Within that radius, GPS begins to experience degraded accuracy^{*}
- Reasonable to insist that Interfering transmitters degrade less than 10% of a region

Adjacent Band transmitters can achieve compatibility (acceptable-degradation) by either:

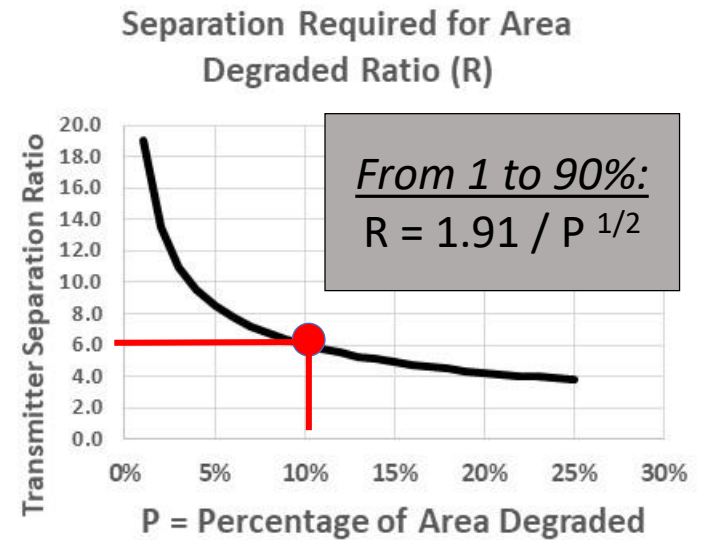
- Constraining Power
- Maintaining greater than minimum spacing between transmitters

*** Degradation begins when interfering power exceeds 25% of the natural Background Radio Noise – (called the 1 dB interference power criterion)**

So, for <10% area degradation,
the Absolute Minimum Spacing or Maximum
Power combination looks like:

This is the "6 Times Rule"

<10% Area Degraded (P) -
Spacing = 6.0 *
Degradation Limit Radius



The DOT Adjacent Band Compatibility (ABC) tests were the only credible set to allow calculations - more than 80 representative GPS receivers

Example of ABC Test Results: Interference "Masks"

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

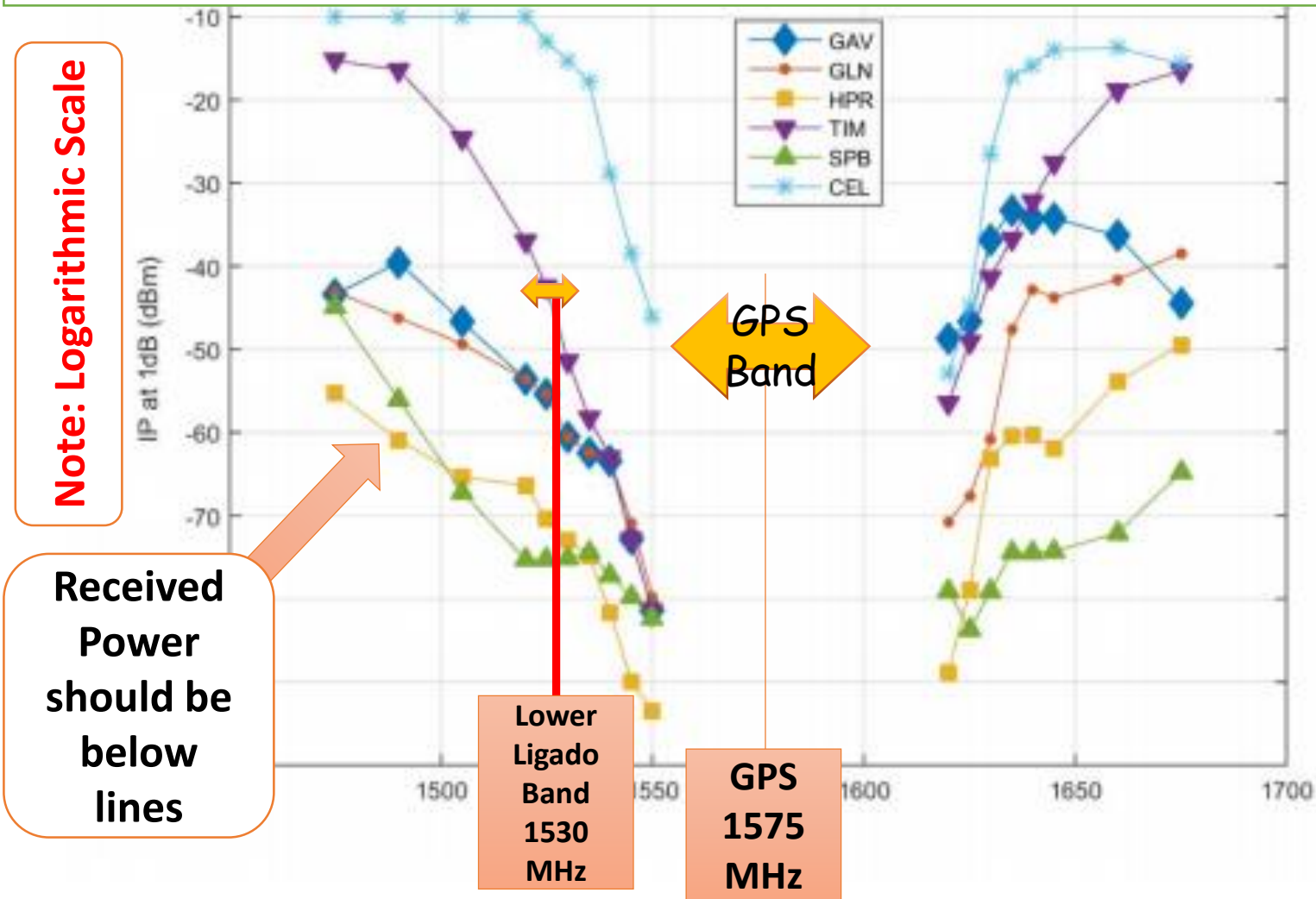
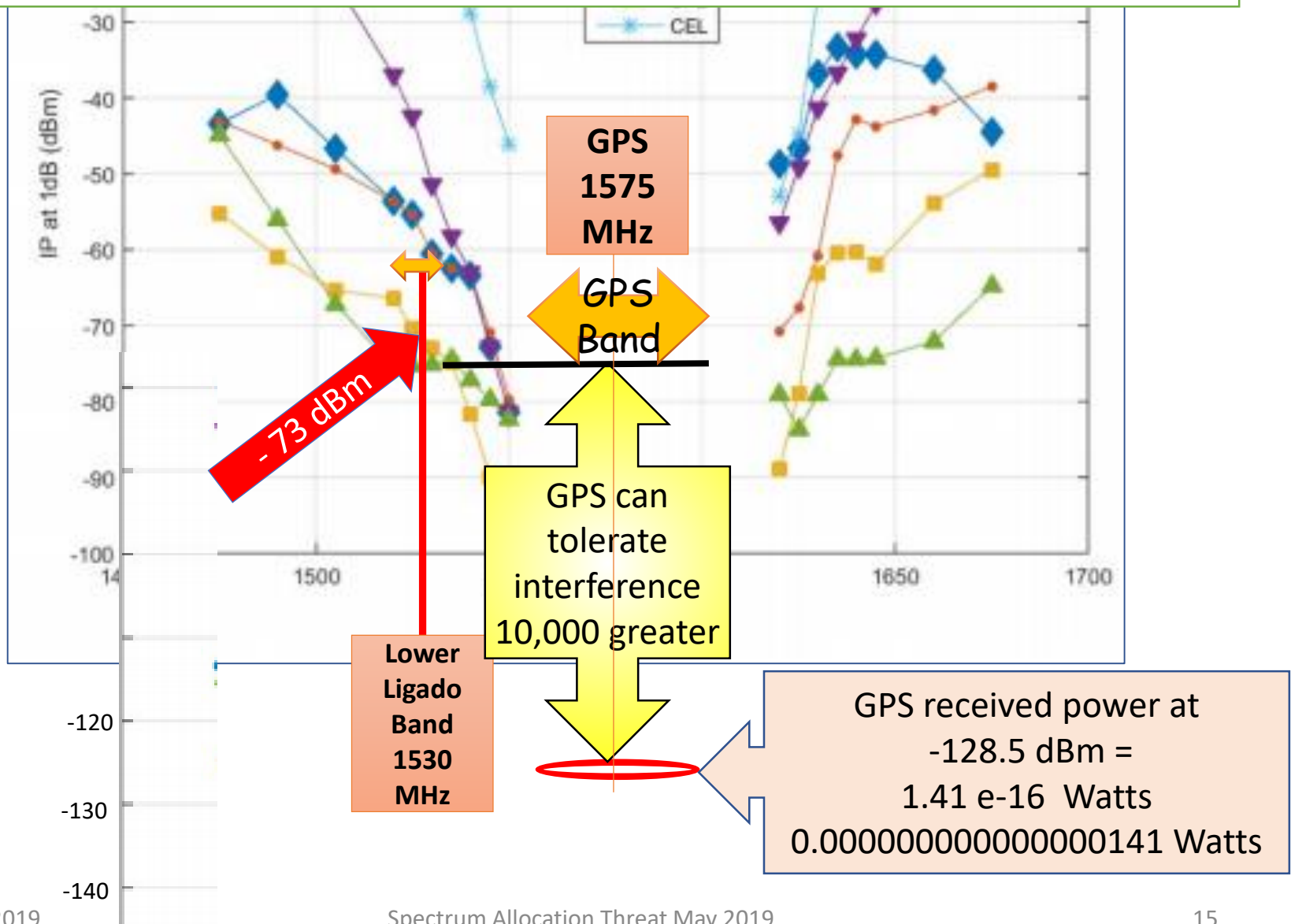
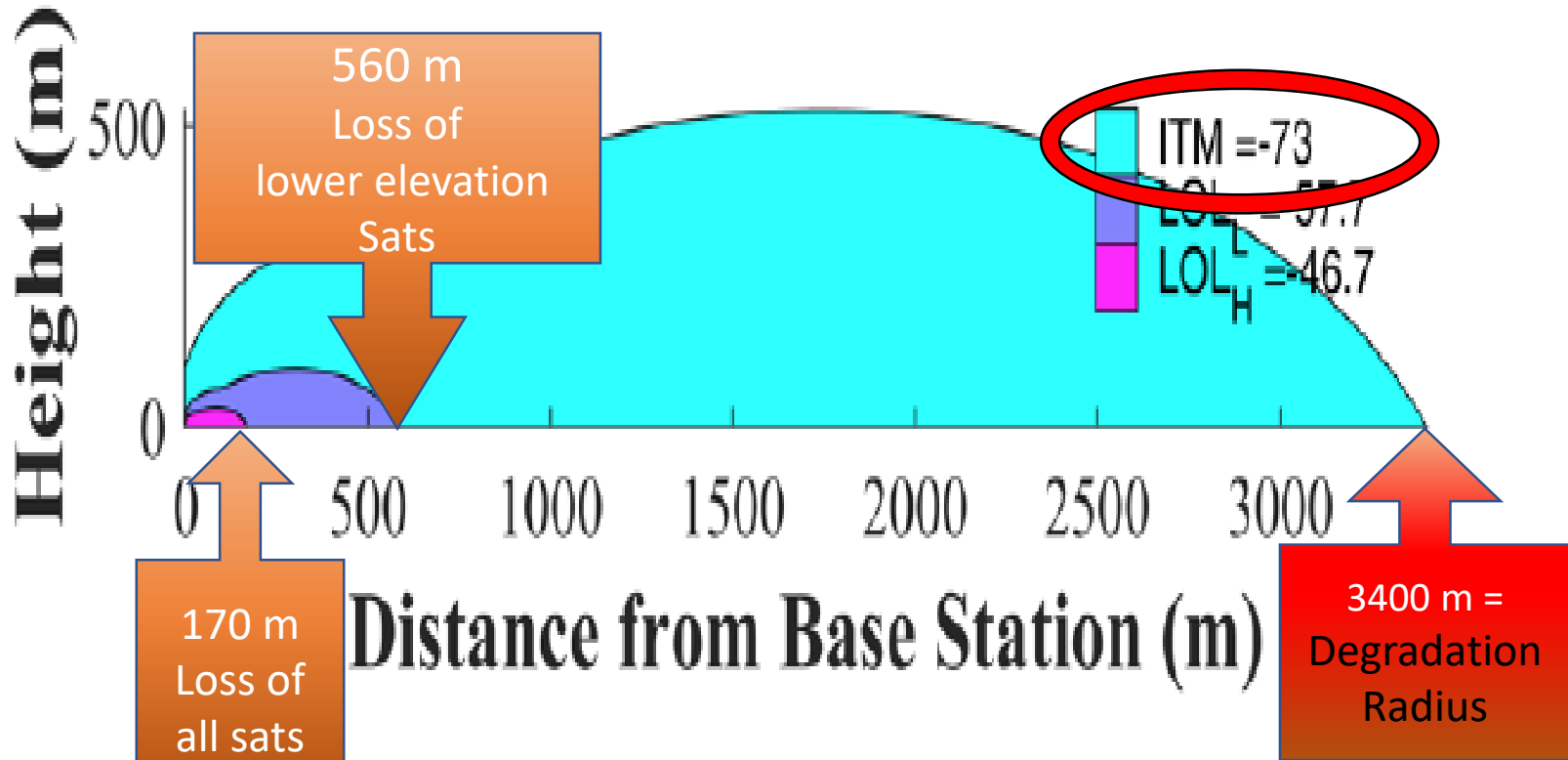


Figure 3-22: GPS L1 C/A bounding ITM for each category of receivers

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



From Appendix I -DOT Test and Analysis:
High Performance Receivers -
 Impacts of **single 10W Ligado micro-Urban** transmitter.
 * Shows that **Degradation Radius is 3.4 Km.**



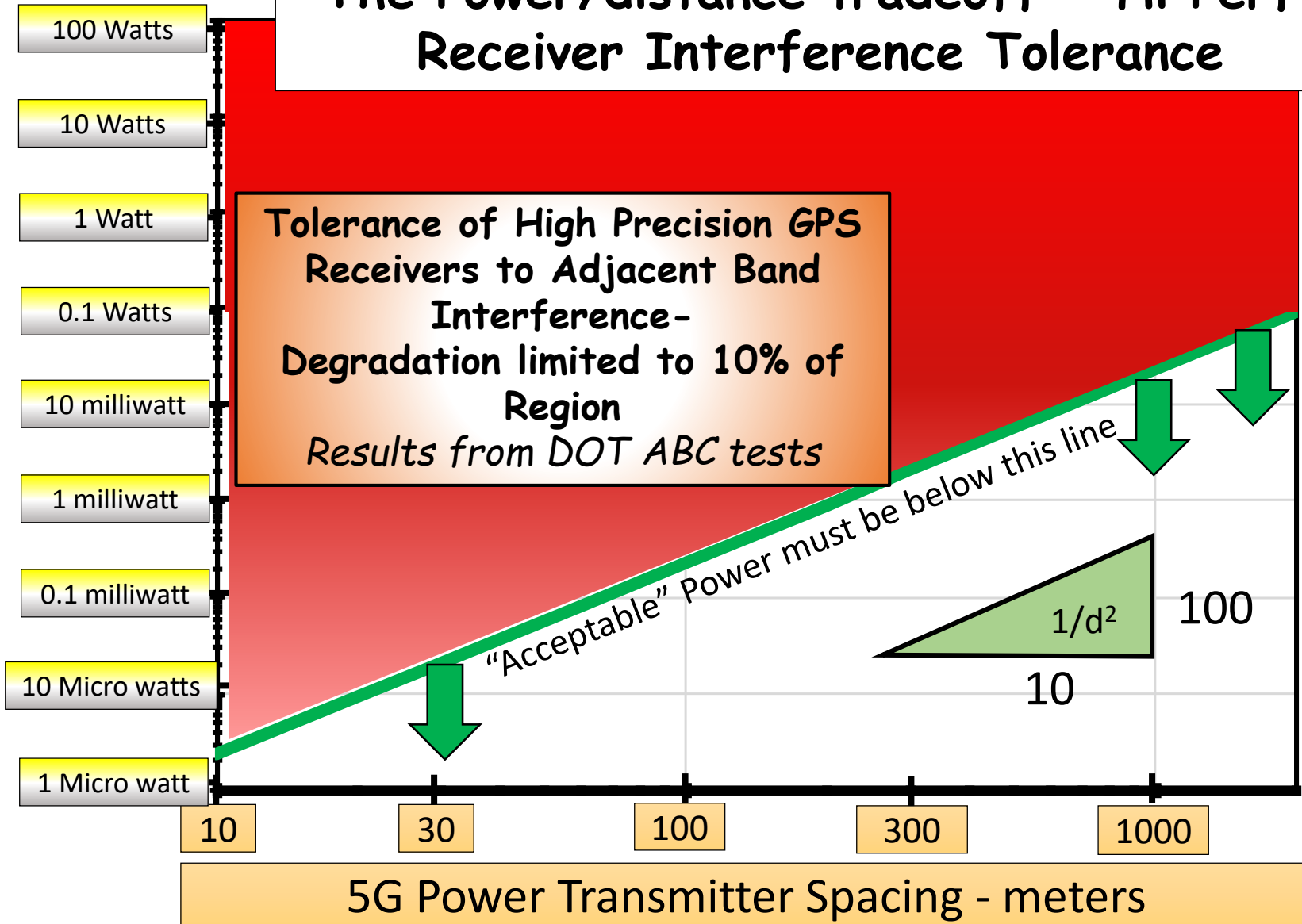
**Figure I-87: Small Cell Outdoor/Micro Urban (EIRP = 40 dBm),
 Bounding HPR, 1530 MHz**

Summary: Hypothetical Tower Spacing Example for High Performance Receivers: Using the 6 times rule.

- 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 5.8 km)**

The Power/distance tradeoff - Hi Perf. Receiver Interference Tolerance



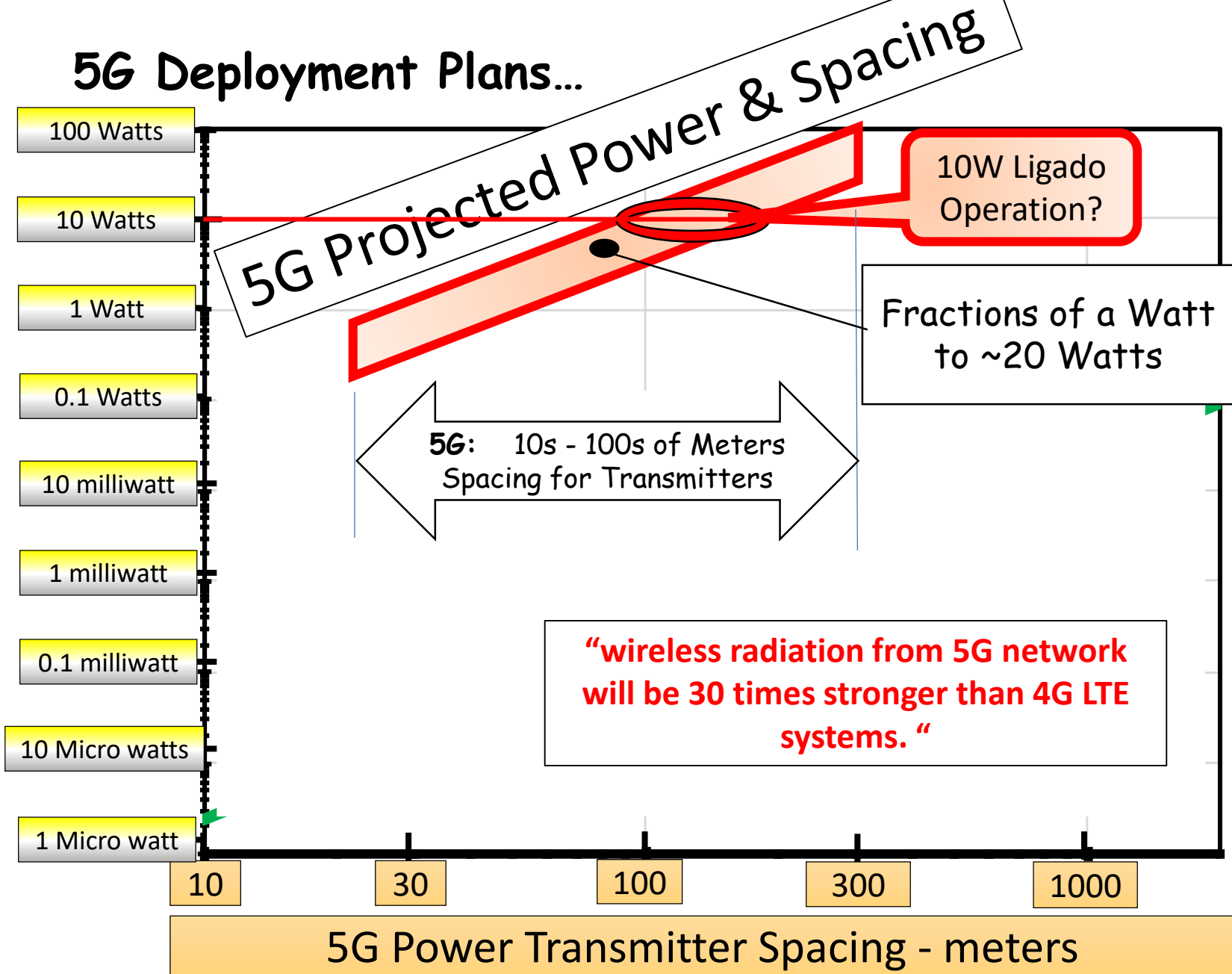
The 5G Revolution -

(It appears that this is Ligado's target for the repurposing of the band)

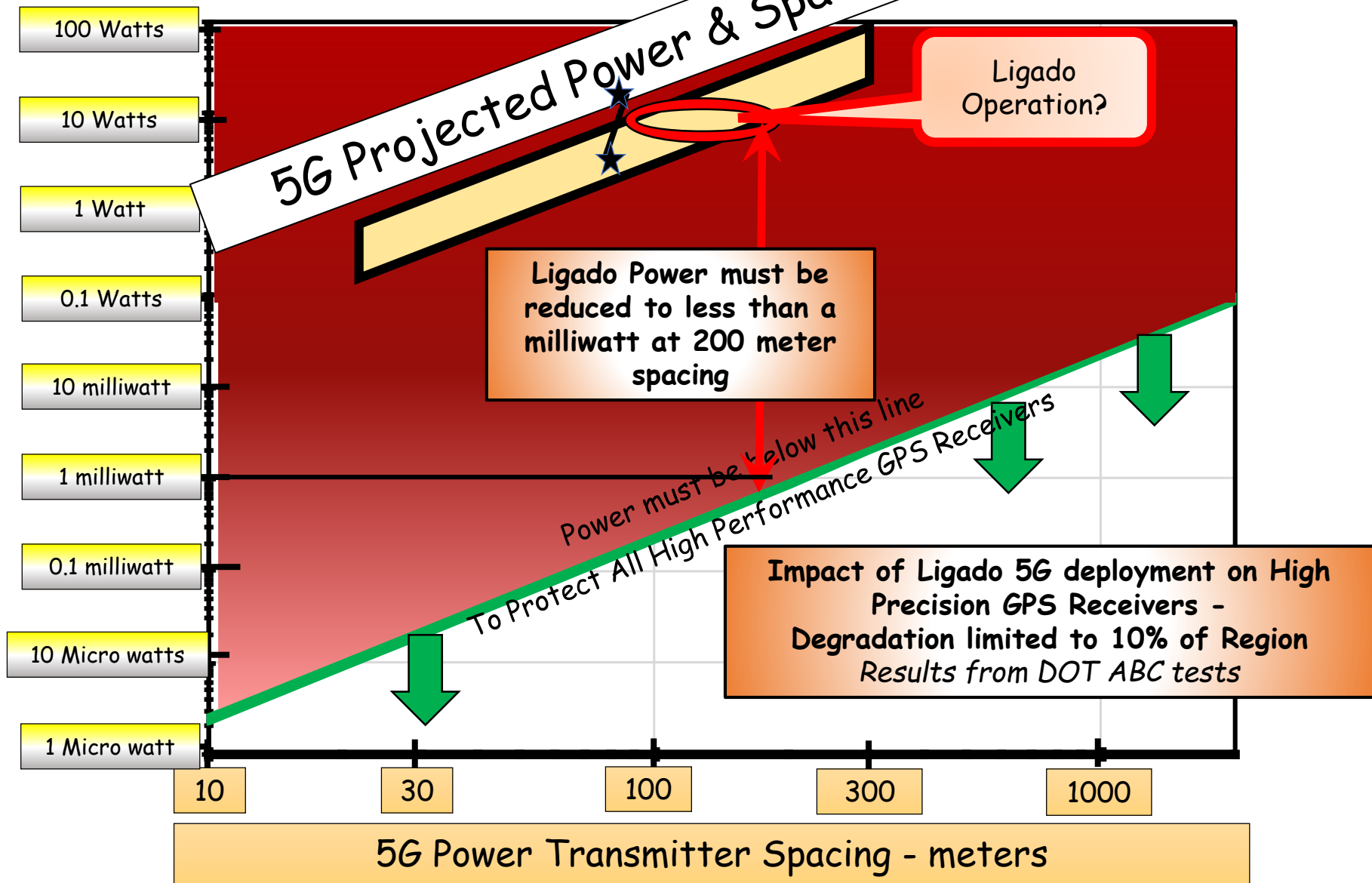
Capability	Description	5G target
Peak data rate	Maximum achievable data rate	20 Gbit/s
User experienced data rate	Achievable data rate across the coverage area	1 Gbit/s

- 5G: "Frequencies from 600 MHz to 14 GHz"
 - GPS is in the middle of this band at 1.5 GHz
- Received power must increase: "wireless radiation from 5G network will be 30 times stronger than 4G LTE systems."
- Expect much greater tower density and higher power to accommodate data rates

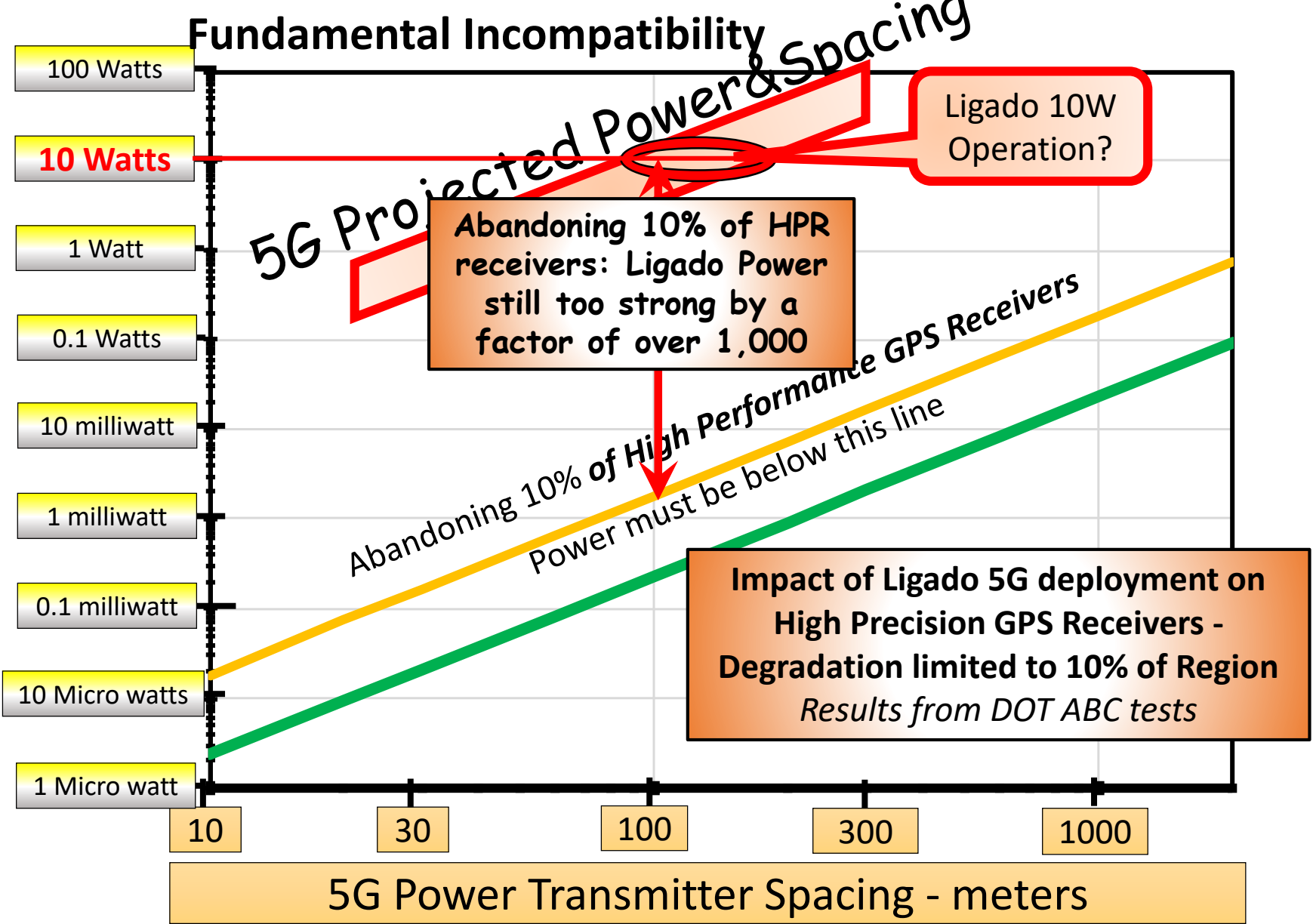
5G Deployment Plans...



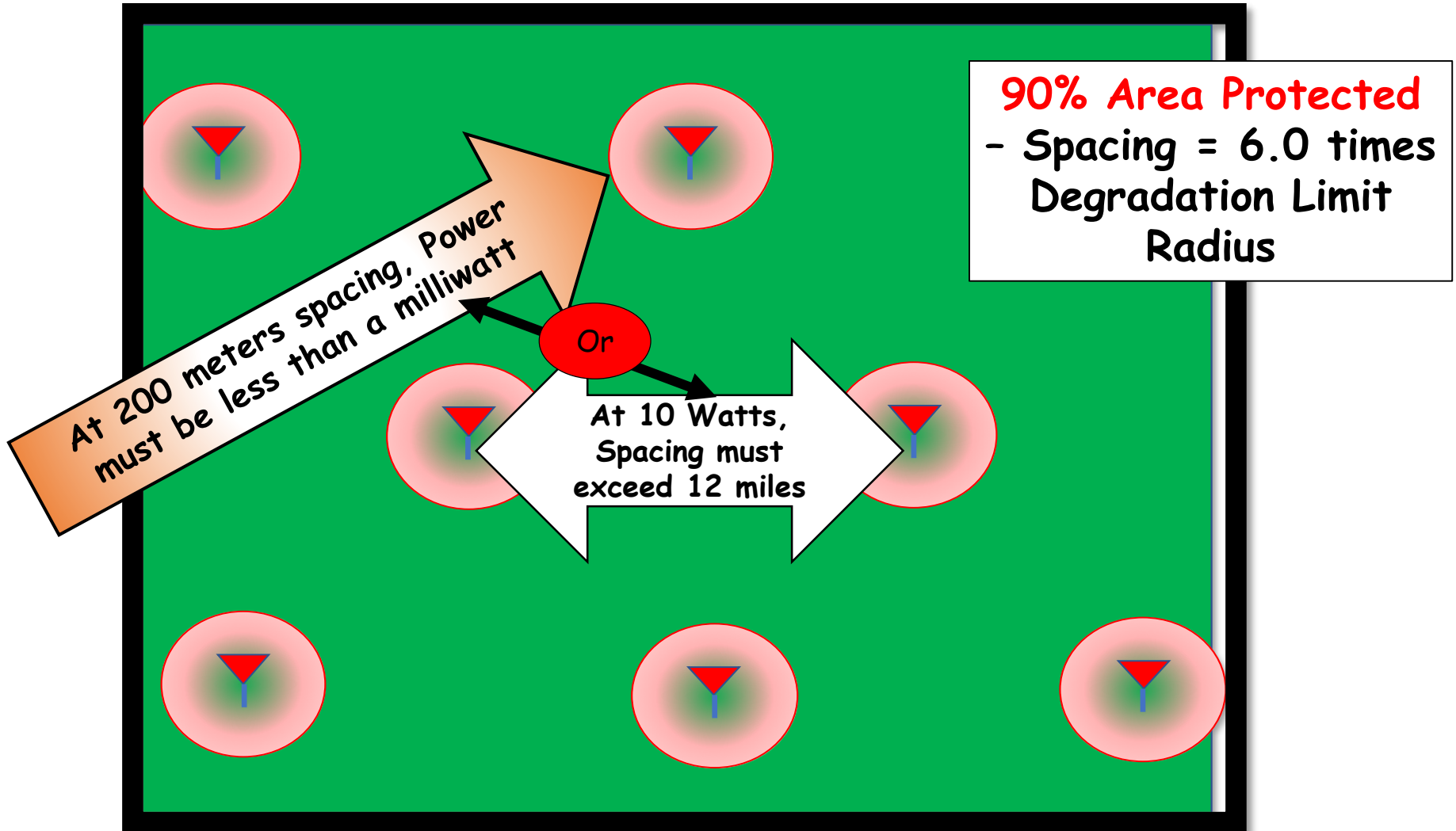
Fundamental Incompatibility



Fundamental Incompatibility



So... Minimum Spacing/Maximum Power for High Performance GPS - combination looks like (2 options):



What about the other
classes of GPS receivers?

Using the "6 Times Rule" & 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 Trans. (ABC report – Appendix I)	<u>Minimum Separation Between Ligado 10 Watt Transmitters (Meters)</u>	
		% <i>Region Vulnerable</i>	
		10%	50%
High Performance/ High Productivity (HPR)	3400 meters	20,481	8190
Emergency Vehicles and General Navigation (GLN)	1045 meters	6295	2815
General Aviation and Helicopters (GAV)	1040 meters	6265	2802
Timing (TIM)	293 meters	1765	789
Cell (CEL)	9.5 meters	57	26

We strongly believe 10% should be the maximum degradation of a region

Good News: The FCC has finally approved the reception of Galileo signals in the US

FCC WAIVER FOR GALILEO

- Granted November 15, 2018
- First waiver of FCC licensing rules under foreign GNSS receiver waiver process established in 2011
- Permits non-federal U.S. receive-only earth stations to operate with specific signals of the Galileo GNSS without obtaining a license or grant of market access
- Based largely on cooperation under GPS-Galileo Agreement
- Request submitted to FCC by Commerce, on behalf of EC, with continual support from State and Commerce
- Benefits all Galileo equipment makers selling in U.S., as well as their customers

Interference may be worse - not included in analysis...

- 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 equally sensitive for HPRs.
- 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 new military signal deliberately pushes energy away from the center frequency, closer to Ligado power.

Agreement: Virtually all known Precision and Scientific user Groups of GPS oppose Ligado Filing because Validated Scientific and Technical Tests Consistently Confirm severe problems

- All Valid testing (AF/DOT - 2011 and 2016) has confirmed Ligado proposal will do severe harm - even at greatly reduced power levels
 - Company sponsored tests met none of the six essential criterion
- Opposition to Proposal to repurpose spectrum:
 - Virtually all Industry Groups associated with Aircraft
 - Advanced applications such as RPVs and self-driving cars
 - Current and previous Generals commanding Air Force Space Command (GPS developers and operators)
 - The previous EXCOM, in spite of extreme political pressure to approve
 - The GPS Program office
 - PNT Advisory Board Et al - see list

And the GPS "Manufacturers", while agreeing to not "Oppose" Ligado, still do not support a Ligado spectrum repurposing that violates the 25% degradation criterion ("1 dB).

(4 of 5 specifically reiterated the International and DOT/DoD Standard)

Partial List: Groups filing opposition to the latest Ligado Filing

- AccuWeather
- Civil Aviation Aerospace Industries Association
- Operations and Safety Airlines for America
- ALERT Users Group
- American Geophysical Union
- American Meteorological Society
- American Weather and Climate Industry Association
- Aviation Spectrum Resources, Inc.
- DTN (formerly Schneider Electric)
- General Aviation Manufacturers Association
- Gogo Business Aviation
- International Air Transport Association
- Iridium Communications, Inc.
- Lockheed Martin
- Microcom Design, Inc.
- Narayan Strategy
- National Air Transportation Association
- National Emergency Number Association
- National Hydrologic Warning Council
- National Weather Association
- Resilient Navigation & Timing Foundation
- Rockwell Collins Inc.
- Satelles Inc.
- University of North Florida
- University of Wisconsin, Space Science and Engineering Center
- Idaho Geospatial Information Office
- Idaho Geospatial Council Executive Commit
- Boeing
- Air Line Pilots Association, International
- Airborne Public Safety Association
- Aircraft Owners and Pilots Association
- Airlines for America
- Association of Air Medical Services
- Helicopter Association International
- Helicopter Safety Advisory Conference
- National Business Aviation Association
- National EMS Pilots Association
- Professional Helicopter Pilots Association
- Users and Stakeholders of Hydrometeorological Information and Technology

Recent Ligado Filings have some significant inaccuracies (1)

- L Statement: "...the record ...regarding Ligado's ...applications is complete ...the Commission therefore should proceed in approving Ligado's applications."
- Reality: While the record in the various Ligado-related proceedings is extensive, there has been no updated Executive Branch position communicated by NTIA to the FCC on interference to GPS. Until that happens, the record is incomplete and the condition of resolving interference to GPS on which the 2011 waiver to LSQ was granted remains unsatisfied. ***The earlier NTIA position clearly recommended disapproval.***

Last Paragraph of most recent (2012) NTIA letter to FCC (added underline)

“Conclusion

The federal agencies and LightSquared have invested significant time and resources to identify and analyze proposed solutions to address the impact of LightSquared's planned network implementations.

Based on the testing and analyses conducted to date, as well as numerous discussions with LightSquared, it is clear that LightSquared's proposed implementation plans, including operations in the lower 10 MHz would impact both general/personal navigation and certified aviation GPS receivers.

We conclude at this time that there are no mitigation strategies that both solve the interference issues and provide LightSquared with an adequate commercial network deployment.”

Recent Ligado Filings have some significant inaccuracies (2)

- Statement: "**Ligado Has Resolved All Concerns Raised in the Record**" ... "Co-existence agreements with the five major GPS device manufacturers, ...testing at NASCTN, and Ligado's adoption of the power level recommended in the DOT Report confirm and ensure that Ligado's proposed terrestrial operations will not cause harmful interference to commercial GPS devices."
- Reality: Many parties continue to formally oppose the Ligado license modification request due to expected interference and unresolved issues. Ligado has adopted only the certified aviation power level in the DOT Adjacent Band Compatibility (ABC) Assessment
 - Ligado's proposal failed by significant margins to meet the interference tolerance limits in the DOT ABC Assessment for all other remaining categories of GPS receivers except cellular.
 - Manufacturer's did not agree to abandon the firm 25% (1dB) interference standard. 4 of 5 specifically reiterated that they supported the International Interference criterion.

Recent Ligado Filings have some significant inaccuracies (3)

- **Statement:** "Moreover, the record demonstrates that GPS is fully protected at 1 dB C/N0 level in the spectrum band allocated to GPS/GNSS (1559-1610 MHz), ..."
- **Reality:** Asserting GPS is protected at the 1 dB standard level in the RNSS band is irrelevant...MSV (now Ligado) reached agreement with some GPS companies, represented then by GPS Industry Council, back in 2004 to limit emissions into the RNSS band to levels that would raise the noise floor no more than 1 dB.
- The issue that has occupied the agencies and public for the past 8+ years, which Ligado's predecessors apparently knew about as far back as 2001 and failed to disclose to the FCC, is receiver overload in the adjacent band caused by excessively high power and unallocated terrestrial service transmissions in the MSS band first proposed by LightSquared (now Ligado) in 2010.

Recent Ligado Filings have some significant inaccuracies (4)

- **Statement** : "All testing shows that the overwhelming majority of non-certified GPS devices will co-exist with Ligado's network, and **the remaining devices can economically be modified or replaced**"
- **Reality**: The majority of receivers in 5 of 6 classes clearly show **incompatibility**. Ligado has not specified transmitter spacing, but it appears they plan to support 5G. The only testing that showed any possibility of compatibility was paid for by Ligado and performed by Roberson and Associates. It did not meet the 6 basic criteria for interference testing that had been established. **All other testing since 2011 shows Ligado's proposal would exceed the 1 dB standard for any reasonable transmitter spacing.**
- There has been no study whatsoever backing the claim that replacement or modification of unprotected devices is economically feasible or practical.

Conclusion: the PNTAB Recommendation Remains Unchanged:

- Analysis of 5G application for Ligado further strengthens our earlier conclusion
- **Reject latest Ligado 10 watt proposal**
 - It does not meet PNT EXCOM January 2012 goal to protect "existing and evolving uses of space-based PNT services"
 - Not even close by a factor of >1000 for 200m spacing
 - And the Laws of Physics ($1/R^2$) are not apt to change...
- Apply DOT/PNT EXCOM Adjacent Band Compatibility (ABC) methodology to any future proposals