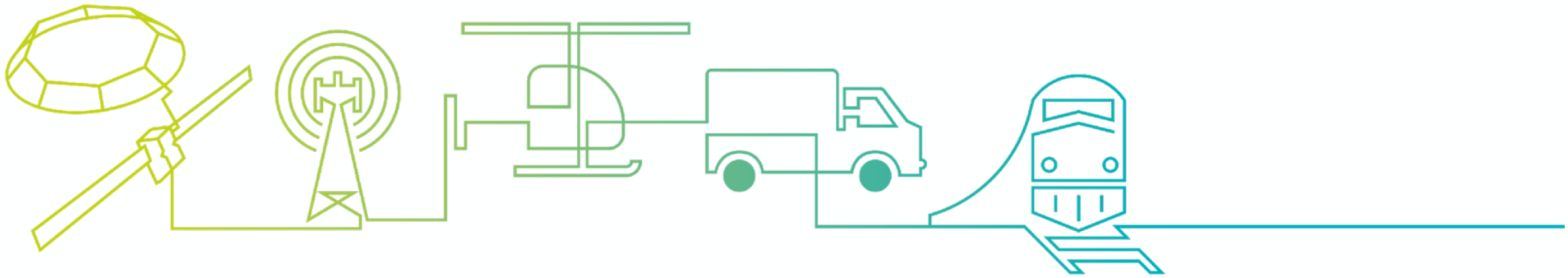
Presentation to the National Academies of Sciences, Engineering, and Medicine

OCTOBER 28, 2021



ligado NETWORKS | Making Stronger Connections

Ligado Networks is a mobile communications company that operates a satellite network across North America providing mobile satellite services (“MSS”) to government, public safety, and enterprise customers.

Building on 25 years of experience supporting the critical communications sector, Ligado is planning to deploy next-generation IoT satellite services and terrestrial-based solutions for both 5G public and private networks using its licensed spectrum in the highly flexible1-2 GHz lower mid-band.

L-Band Supporting Companies in 3GPP

NOKIA
intel
SAMSUNG
Jio
MEDIATEK
ERICSSON
SEQUANS COMMUNICATIONS
Globalstar

Technology Partners

HUGHES
NOKIA
MAVENIR
Rakuten

Customers

U.S. Immigration and Customs Enforcement
FEMA

Topics for Discussion

1. **Technical Resolution of Harmful Interference Concerns and How the FCC Order Protects GPS**

2. **Additional Safeguards Imposed by the FCC Order**

3. **Discussion of Harmful Interference**

Introduction: Important Perspectives on Resolving Harmful Interference to GPS

Julius Knapp (Former FCC OET Chief):

- "During the decade preceding LightSquared's November 2010 waiver request, the GPS industry had numerous opportunities to inform the Commission of the receiver overload issue. Despite participating extensively throughout these proceedings, and raising other interference issues that were ultimately resolved, it did not do so…Now, as I have mentioned in this instance the interference is caused by GPS receivers picking up signals outside of the GPS band." (*See* Congressional testimony on September 21, 2012)

Brad Parkinson (Co-Chair, PNT AB and one of the key developers of GPS):

- "The GPS community is willing to adjust but not with a gun at their head where you are allowed to pull the trigger tomorrow." Politico reported that Brad Parkinson said with more testing and if the GPS community "was given enough time" to retool its equipment—a process Parkinson said would take "five to 10 years", then "he and the PNT Advisory Board could get behind [terrestrial use of this spectrum]." (*See* Politico, October 28, 2011)

Javad Ashjaee (Former CEO of Javad GNSS):

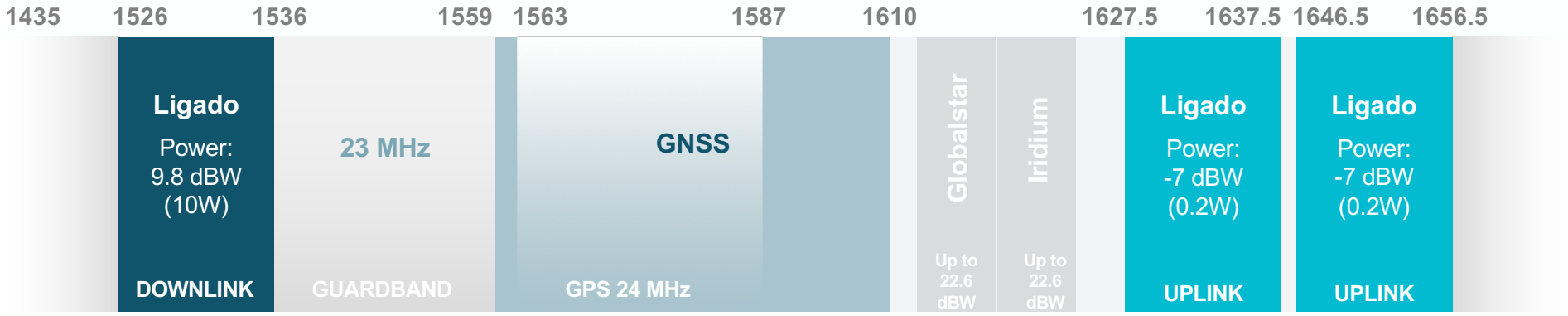
- "Despite the GPS industry's claims that it would take 10 years and tens of billions of dollars to find an engineering solution, I found a technical solution in a few weeks, using existing technology and off-the-shelf materials." (October 18, 2011)

Ashton Carter (Former Secretary of Defense)

- In an interview, Defense Secretary Ashton Carter said, "I hate GPS. The idea that we are all hooked to a satellite — formerly bought by me to my great resentment — in a semi-synchronous orbit that doesn't work in certain circumstances, does not work indoors or in valleys in Afghanistan, is ridiculous. I think that 20 years from now we won't be buying GPS satellites. Twenty years from now everything you have that is manufactured for you, including your phone, will have on the chip a clock, a gyro and an accelerometer." (*See* "How Government Drives Innovation" (June 24, 2014)

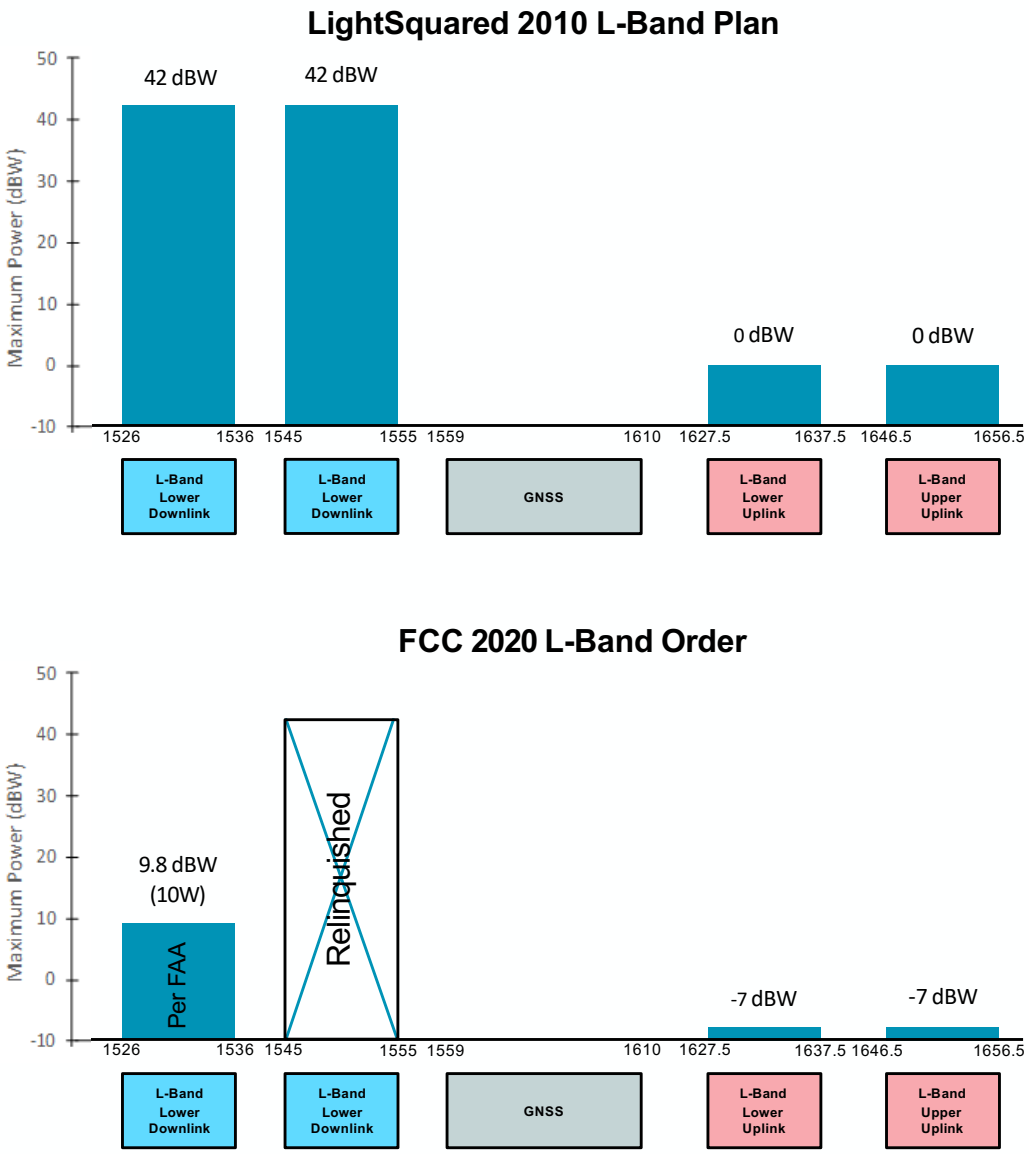
Technical Resolution of Harmful Interference Concerns and How the FCC Order Protects GPS

L-Band Spectrum Map



Not drawn to scale

There are Major Differences Between the 2010 LightSquared Plan and the 2020 Ligado Plan Approved in the FCC Order—and They All Protect GPS



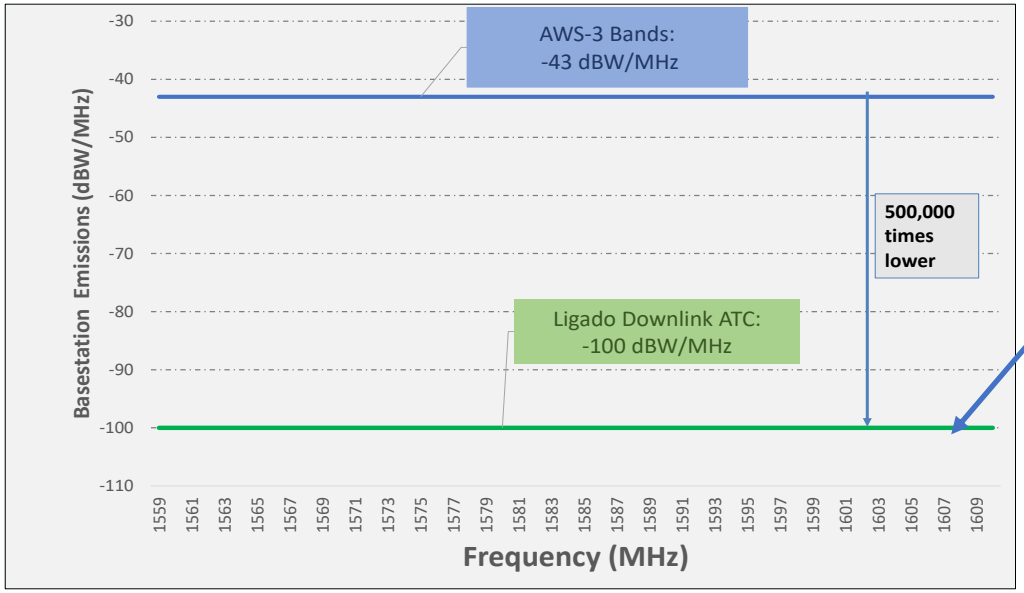
FCC Order Protects GPS:

- 23 MHz guardband created to protect the GNSS band because Ligado agreed to use 1545-1555 MHz for satellite only and not for ATC as previously authorized by the FCC
- Lower power in all channels
- Certified Aviation GPS devices (safety of life) protected at 9.8 dBW (10W) per DOT ABC Report

Note: Distances Between Spectrum Bands Are Not To Scale

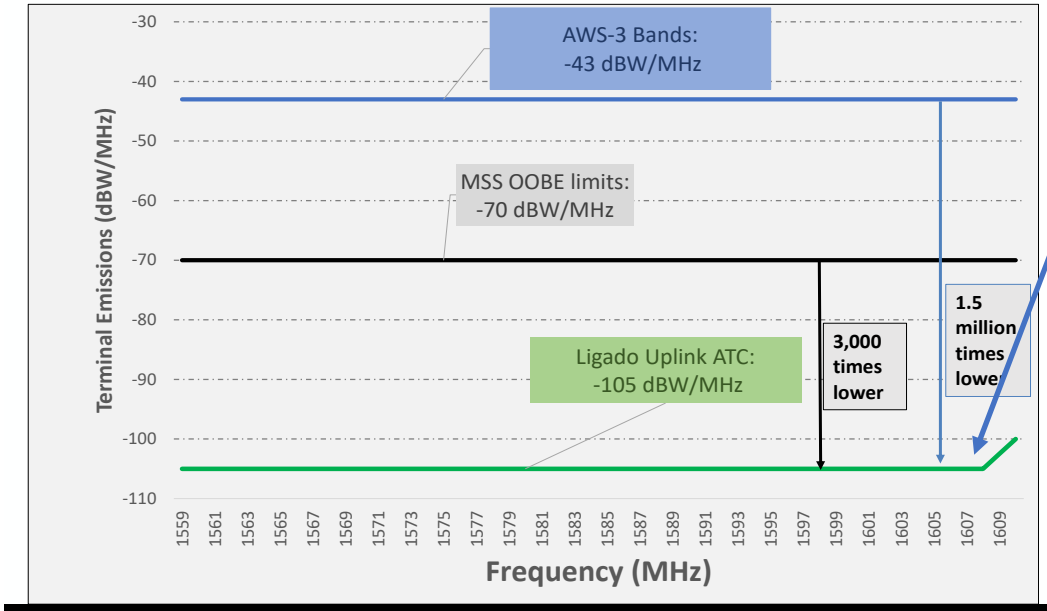
Ligado Also Reduced its Out of Band Emissions—the Reductions Made Ligado's OOBE's into the GNSS Band Much Lower Than Any Other Spectrum User's

Base Station Emissions in the GNSS Band



Our base station emissions into the GNSS band are significantly lower than base station emissions from other nearby operators

Terminal Emissions in the GNSS Band



Our user terminal emissions into the GNSS band are significantly lower than terminal emissions from other nearby MSS and ATC operators

AWS-3 Uplink Band closest to GPS: 1695 – 1710 MHz

Prior to Seeking FCC Approval, Ligado Addressed the Harmful Interference Concerns of All Key Stakeholders

1

Industry Concerns

Ligado approached the GPS industry leaders to understand and then address their technical concerns about harmful interference

2

Certified Aviation

Ligado agreed to defer to the FAA's assessment of the right power level to protect certified aviation GPS devices

3

Issues raised in the 2012 NTIA Letter to the FCC

The NTIA outlined areas of concern and was clear that these could be resolved through collaboration and accommodation; Ligado followed the NTIA's road map to do just that

Specific Technical Concessions Requested by GPS Industry and/or USG Stakeholders

- Ligado's 2015 Proposal was developed through technical discussions with the GPS manufacturers and USG agencies
  - Garmin, Deere, Trimble actively participated in detailed technical discussions with Ligado and reached co-existence agreements
  - Other major GPS manufacturers later signed off, including NovAtel, Hexagon, Leica, TopCon, Septentrio
- Relinquishment of the Upper Downlink (1545-1555 MHz)
  - Requested by all three GPS manufacturers to protect GPS devices operating in the GNSS band
  - Created a 23-MHz guardband for GPS; effectively gave GPS 23 megahertz not allocated to them by the FCC
- Lower Power and Reduced OOBE in the Uplink Spectrum Bands (1627.5-1637.5 MHz and 1646.5-1656.5 MHz)
  - Requested by all three GPS manufacturers to protect GPS devices operating in the GNSS band
  - Garmin requested and was given five years additional time to ramp up to the agreed-upon power on the lower five megahertz of the lower uplink (aka "the Garmin notch") so that it could prepare certain of its devices to co-exist with Ligado
  - DOD (Army, Navy, Air Force), DOC, and NASA signed off on Ligado's proposed use of the Uplinks in 2013 (*see* Appendix C at 41-44)
- Lower Power in the Remaining Downlink (1526-1536 MHz)
  - Garmin and Deere agreed that 32 dBW would protect their GPS devices (other than certified aviation GPS receivers)
  - Ligado committed to work with the FAA to determine the safe power level for certified aviation GPS devices
  - Ligado and the FAA collaborated to determine safe power level; the FCC Order adopted the recommendation in the DOT ABC Report
- GPS manufacturers never indicated that they could not co-exist with Ligado or that there were technical issues that could not be solved
  - They sought and were given power and OOBE concessions, for time to prepare, and for advance notice of Ligado's deployments
  - DOD CIO officials requested that Ligado submit testing by NASCTN and indicated that it did not support the DOT ABC testing
- Ligado agreed to all of the GPS manufacturer requests
- USG endorsed all of the concessions made by Ligado; NTIA and DOD CIO worked collaboratively with Ligado and the FCC until 2019

What the GPS Companies Said About the Ligado Proposal

GARMIN	"Garmin spokeswoman Carly Hysell said [Ligado's] agreement to cut out-of-band emissions and power levels in the spectrum band closest to the GPS signal protects the interests of GPS users, and the company doesn't anticipate any performance-degradation issues for those using GPS technologies." *Wall Street Journal* (12/17/15)
JOHN DEERE	"Deere herein confirms that it does not oppose grant of the Modification Application, as proposed, that would incorporate the full set of technical parameters and licensing conditions …" *Deere Reply Comments* (6/21/16)
Trimble	"Trimble continues to support the adoption of the Agreed License Conditions … Taken as a whole, the Agreed License Conditions represent a compromise which balances the competing public policy interests raised by Ligado's proposed use of its licensed spectrum." *Trimble Reply Comments* (6/21/16)
NovAtel	"We are pleased to report that after considerable discussion and analysis [NovAtel and Ligado] have reached a co-existence agreement which calls for future coordination … On the basis of this understanding, NovAtel supports Commission granting of the modification applications." *Joint NovAtel/Ligado Ex Parte Filing* (6/27/16)
TOPCON	"Over the past many months, we've worked closely with Ligado to conduct a thorough analysis. We've agreed that the parties will cooperate in the future if their proposal impacts TopCon's operations in any way. Our agreement is a positive step forward for both companies, and we look forward to coordinating with Ligado over the coming years as it deploys a ground network." *Chief Strategy Officer Ivan Di Federico*, Press Release (12/6/16)
septentrio	"Radio interference is everywhere. GSM, LTE, FM broadcast radio, VHF/UHF communications, Wi-Fi, satellite phones and GNSS signals are all competing for a finite space on an already heavy populated radio spectrum…. At Septentrio, we devote considerable attention to interference throughout the design of our equipment. Working with customers over many years to solve real problems, we have developed Advanced Interference Mitigation (AIM+). These algorithms counteract the effects of interference." *Targeting Interference with AIM+,* (December 15, 2015) (http://www.septentrio.com/insights/targeting-interference-aim).

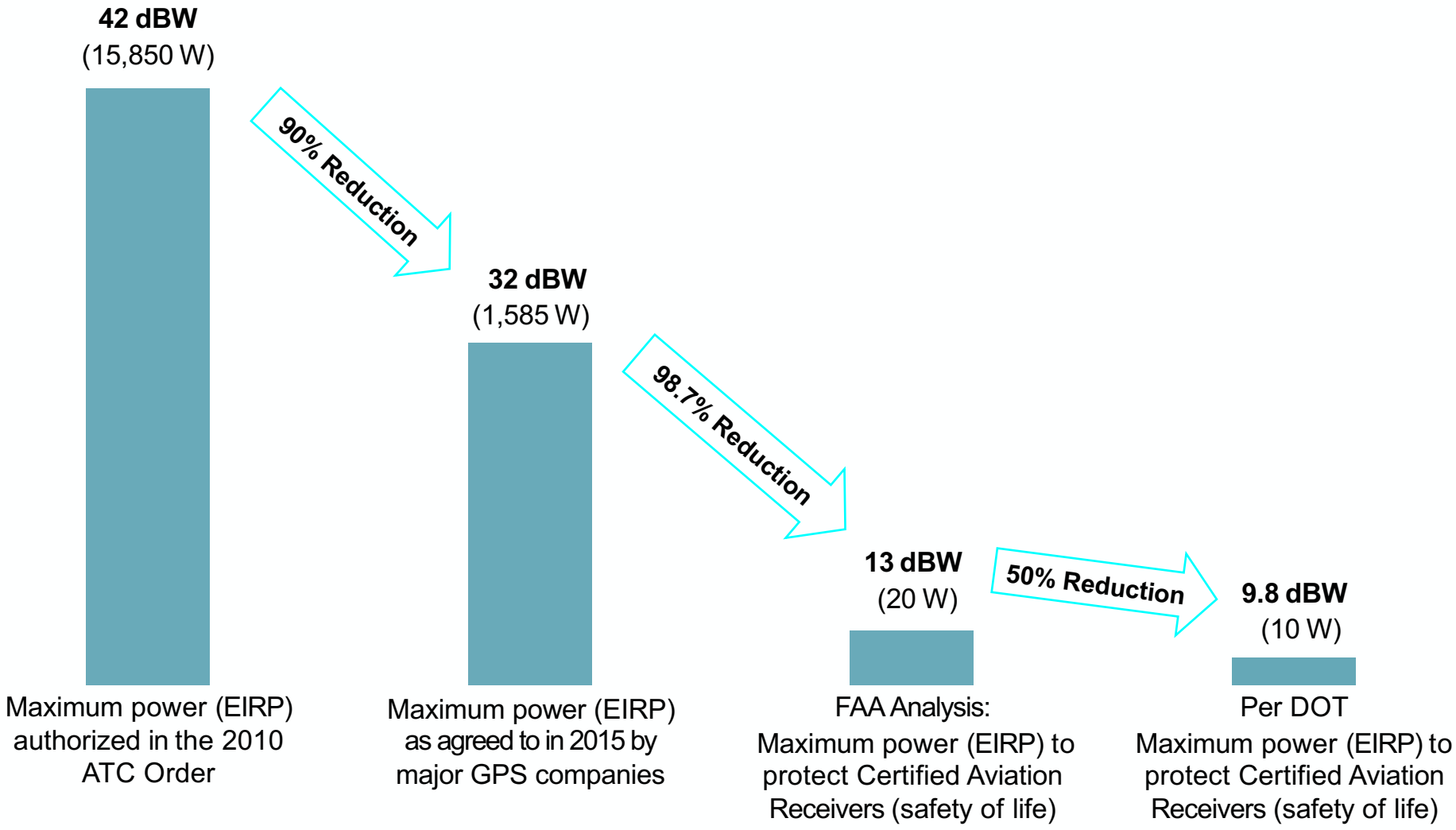
More Recent Perspectives from GPS Industry on Ligado and GPS Co-existence

- "Septentrio hardware and Ligado services are complementary. Septentrio has worked with Ligado to refine certain of Ligado's high-precision offerings. We are aware of Ligado's proposed operating parameters and have reviewed them against our existing and continuously evolving technology to protect GNSS receivers against a variety of disturbances. Ligado's proposed operating parameters fall within the type of interference GNSS receiver can be immune to by design. In fact, we are pleased to be able to distinguish ourselves in the market on the fact that our precision receivers are designed and have proven to be robust in challenging RF environments, including with respect to terrestrial adjacent band emissions." *Septentrio* (2018)
- "The result of our analysis and those discussions was an agreement with Ligado that led us to develop tools to mitigate the impact of intentional or unintentional interference within the GNSS band. This technology helps to maintain high-quality multi-frequency, multi-constellation positioning performance in challenging RF environments, although these mitigation steps do come at a penalty of size, weight, power, and cost. Independent of Ligado's proposed operations, GPS device makers must continue to refine their devices and receivers to combat all sources of interference." *Novatel* (2018)
- "J-Shield is a robust filter on Javad GNSS antennas that blocks out-of-band interference. J-Shield blocks signals that are near the GNSS bands, including the proposed Ligado Networks (formerly LightSquared) broadband signals, explained Javad Ashjaee, founder and CEO of Javad GNSS." *Javad* (2019)
- "Tallysman Wireless announced its new extended Filtering (XF) features to the TW3900 series of Accutenna precision antennas. The XF feature is designed to mitigate interference from all near-band signals." *Tallysman* (2021)
- "Interference-rejecting antennas are the first line of defense against out-of-band interference and GPS disruptions," said Kathleen Fasenfest, Antcom's chief engineer. "Our high-filtering antennas offer advanced interference robustness to protect against current and future signal crowding on the RF spectrum. These antennas are available off-the-shelf for simple integration with standard GPS receivers and existing positioning systems." *Antcom* (2021)
- MITRE agrees that receivers can be designed to co-exist with adjacent band operations. *See* Ian T. McMichael, Erik Lundberg, Drayton Hanna, and Steven Best, MITRE Corporation, Horizon Nulling Helix Antennas for GPS Timing (2017) (describing a "helix" antenna system for GPS timing devices capable of resisting interference from both unintentional and intentional sources of interference)

FAA and DOT Determined that 9.8 dBW Protects Certified Aviation GPS Devices

- Ligado engaged in lengthy discussions and technical analysis with the FAA and the aviation community over several years to calculate a Ligado operating power that would protect certified aviation GPS devices
  - Certified GPS devices are the only GPS devices pilots are permitted by FAA regulation to rely on for position/location information
  - The lower downlink (1526-1536 MHz) is the only band that was at issue for aviation—the uplink operations have no impact on aviation and interference concerns about the uplink were resolved by the GPS agreements and signed off on by DOD, NASA and DOC in 2013
- The FAA analysis was based on the most restrictive use case – helicopters operating in unlikely scenarios
  - Whereas fixed wing aircraft are prohibited from operating closer than 500 feet from any obstacle (including a radio tower or base station), helicopters are permitted to fly closer than that
  - To ensure protection of all certified devices, the Ligado power was determined by using a series of worst-case assumptions for helicopter operations that included proximity to tower, characteristics of surrounding terrain, minimally compliant GPS receiver, helicopter positions relative to base station antenna and a probabilistic distribution of results
- The analysis and resulting power level included several safety margins
  - One of them—for helicopters operating in level flight was a full 6 dB reduction in power
- FCC approved power level of 9.8 dBW was the power level recommended in the DOT ABC study to protect certified aviation devices
  - While the FAA found that base station power levels in the range of 9.8 to 13 dBW would protect certified aviation devices, DOT adopted a more conservative power level of 9.8 dBW in its final ABC Report
  - The FAA's analysis (including all safety margins and worst-case scenarios) produced a range of safe power levels that were dependent on the height and orientation of base station antennas. The 9.8 dBW power level used by the DOT in its ABC study represented the lowest power level of this range
- Based on this analysis and to ensure aviation safety, Ligado and then the FCC adopted the DOT's recommendation power levels

Lower Downlink Power Limit was Determined Through Extensive Work with the FAA



9.8 dBW (10 W) is a 99.94% reduction from the power level in the GPS co-existence agreements

The FCC Order Protects All Categories of GPS Devices

The FCC determined that Ligado's proposal addresses harmful interference concerns with respect to GPS operating in the GNSS band (¶ 2):

- For cellular*, the FCC concluded "that there is little or no potential for harmful interference from Ligado's modified ATC base station or handset operations to the hundreds of millions of cellular devices in the marketplace" (¶ 88)
- For general location and navigation (GLN)*, the FCC concluded "that Ligado's modified ATC network should not cause harmful interference to general location and navigation devices (including general non-certified aviation receivers)" (¶ 88)
- For high-precision, the FCC found "that receivers should be able to co-exist with Ligado's modified ATC network operations in the adjacent spectrum" (¶ 89)
- For certified aviation, the FCC:
  - Affirmed that Ligado "worked with the FAA and that agency's advisory panels for more than a year to develop an approach to ensure that Ligado's operations protected certified aviation GPS receivers, including helicopter operations" (¶ 14)
  - Found that the DOT Report did conclude that 9.8.dBW is the safe power level to protect certified aviation devices (specifically, HTAWS, which is the most restrictive of the certified aviation scenarios, requires a downlink EIRP limit of 9.8 dBW (10 W) (cross-polarized) at 1531 MHz and minimum inter-station separation distance of 433 meters (1420.6 feet) for fixed location base stations in a hexagonal grid to protect from harmful interference certified aviation GPS receivers operating in accordance with applicable MOPS) (¶ 66)
  - Recognized that the FAA came to these conclusions based on the most restrictive scenarios involving helicopter flight near Ligado's base stations (¶ 72)
  - Concluded that this power level also protects military aviation applications (¶ 105)

*Cellular and GLN devices comprised approximately 99% of all GPS devices in 2015

Additional Safeguards Imposed by the FCC Order

FCC Imposed Stringent License Conditions that Protect GPS

Technical Operating Conditions (¶ 134, 136, 139, 141)

- 23 MHz guard band between Ligado's terrestrial transmission and GPS operations
- Reduction of power levels by > 99.3% from the 32 dBW power level proposed in 2015 License Modification Applications
- Restrictive out of band emissions (OOBE) into the GPS band

Coordination with Federal Agency GPS Users (¶ 144)

- Replace or repair expeditiously U.S. Government GPS devices, as needed, in case of harmful interference
- Launch an information exchange program with USG by October 21, 2020

Coordination with GPS Device Manufacturers (¶ 145)

- At least six months advance notice regarding the activation of base station to:
  - Garmin, Trimble, Deere, NovAtel, Topcon, Hexagon Positioning Intelligence, Septentrio, Leica
  - Any other GPS manufacturing company that Ligado knows could potentially be affected by Ligado's ATC network operations
  - Advance notice to include Ligado's terrestrial network coverage maps

Respond to Notification of Interference Complaints (¶ 146)

- Ligado toll free number for reporting incidences of interference to GPS operations from Ligado's operations
- 24x7 notification to report, investigate, validate and resolve any GPS disruption within one hour to FCC
- 24x7 "cease buzzer" to cease all base station transmissions in the event of a "large-scale" disruption to GPS capability within 15 minutes of an FCC operations request

The FCC Addressed the DOD's Purported Concerns About Harmful Interference to GPS

The FCC stated clearly that the DOD has not provided any information to support its vague assertions that a "vast" number of GPS systems will be impacted (¶ 100) and that devices DOD is talking about are operating outside their allocated spectrum

- The FCC found that the three April 2020 letters from the DOD did not provide any new data for the FCC to evaluate (¶ 46) and were based on an "inappropriate" metric and an outdated proposal, including much higher power levels than Ligado is proposed, and the FCC approved. (¶ 100)
- The FCC explained how the data shows that devices which seem like they could be impacted are operating outside the spectrum allocated to them by the FCC. (¶¶ 50, 56, 57)
- The FCC acknowledged that in 2010, the DOD and NTIA agreed that GPS devices were not entitled to protection outside their band and noted that no one has ever refuted this agreement. (¶ 52)
- In the event it is determined that Ligado's operations will cause harmful interference to a specific, identified GPS receiver operating on a military installation, Ligado and the affected government agency will need to negotiate an acceptable received power level over the military installation or a limited exclusion zone will need to be established. (¶ 103)
- Nonetheless, the FCC required Ligado to repair and replace DOD devices that could experience harmful interference
  - The FCC also urged federal agencies to exchange information with Ligado to facilitate the repair and replacement of devices.
  - On three separate occasions since the FCC Order was issued, Ligado has requested information from DOD regarding devices that need to be repaired and replaced but DOD has not provided any information and has declined to exchange any technical information with Ligado.

Discussion of Harmful Interference

Summary of the Flaws of 1 dB

Why did the FCC not accept 1 dB C/N_0 as the metric for harmful interference?

Because testing, including testing conducted by the DOD & NTIA-sponsored NASCTN tests, demonstrated 1 dB C/N_0 was not a valid indicator of harmful interference or a reliable metric

Data showed that 1 dB C/N_0 degradation did not correlate to errors made by GPS devices, meaning the 1 dB C/N_0 metric does not correlate with harmful interference.

The 1 dB C/N_0 metric is not reliable. Testing revealed that the error variability of GPS devices can be as much as 2-3 dB. That's like a poll showing a 51-49% lead with a margin of error of +/- 5% -- which makes the polling difference irrelevant.

Neither the FCC nor ITU has ever used the 1 dB C/N_0 metric for determination of harmful interference to adjacent bands.

What is Harmful Interference and Why is it the Right Standard?

Both the FCC and NTIA use the harmful interference standard and have for decades

- Both adopted verbatim the same definition of harmful interference provided by the International Telecommunications Union (ITU) Radio Regulations

- The FCC's harmful interference standard is set forth at 47 CFR § 2.1(c):
  - **Harmful Interference** is "Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations"

- The NTIA's definition of harmful interference is found in the Manual of Regulations and Procedures for Federal Radio Frequency Management (Redbook), which also states:
  - "The Federal Government considers that the basic guide to follow in the normal assignment of radio frequencies for transmission purposes is the avoidance of harmful interference and the use of frequencies in a manner which permits and encourages the most beneficial use of the radio frequency spectrum in the national interest." *NTIA Redbook* § 2.3.6.3; *see also id.* § 6.1.1 (including the same definition of "harmful interference" as the FCC).

- As the FCC has explained it, harmful interference is "different and distinct" from mere "interference," and concerns "whether the actual performance" of a device is affected. *Order* ¶¶ 35, 48. For this reason, the FCC's Order focused on "demonstrable evidence of how the functioning of [a GPS] receiver is endangered, seriously degraded, or repeatedly interrupted." *Id.* ¶ 59.

What is the Right Way to Measure Harmful Interference? Assess whether the GPS Device Able to Function.

- Key Performance Indicators:
  - Two of the tests considered by the FCC evaluated the impact of Ligado's operations on the ability of GPS devices to accurately report location or timing data to the user. Based on a GPS device's intended purpose, this metric was determined to be the key indicator of whether a GPS device was functioning.
- Roberson and Associates KPIs:
  - "We developed our plan for testing GPS key performance indicators based on a transparent, iterative process that took into account feedback from a wide variety of stakeholders. We shared our initial outline of testing procedures with the Commission, the Department of Transportation ("DOT") and other organizations in June 2015,[1] filed a draft test plan with the Commission in August 2015,[2] conducted an open discussion regarding the test plan at DOT's October 2, 2015, workshop on adjacent band issues, and filed a revised test plan with the Commission in February 2016.[3] At each stage of the process, we and Ligado encouraged device manufacturers and other interested parties to provide feedback and any available technical data — on a confidential basis to RAA only, as needed — to make our study as robust as possible." (Section 2.1)
  - "Because of variations in the use cases for different classes of GPS devices, the precise KPI definition varies among these classes.
    - → GLN: The KPI for this class of device is two-dimensional position error while the device was in simulated motion.
    - → Cellular: Industry-standard KPIs for GPS performance in cellular devices are set by the 3GPP.[4] We performed three tests defined in 3GPP Specification TS 37.571-1, which measure device sensitivity, accuracy, and dynamic range. Success in these tests is defined by the Specification as the device limiting two-dimensional position error and maximum response time below certain thresholds under defined conditions at least 95% of the time. The 3GPP tests require the device to make phone calls and respond to requests to report position. Since the Samsung Tablet (a cellular device) could not make phone calls and perform the 3GPP tests this device was tested for two-dimensional position error in the presence of LTE signals.
    - → High Precision: The KPI for this class of device is three-dimensional position error.
    - → Non-Certified Aviation: The KPI for this device is two-dimensional position error."
  - "In addition to the KPIs set forth above, we recorded other information, such as C/N_0 values and the number of satellites received, to the extent the tested devices reported such statistics in a format accessible to third parties." (Section 2.2)

What is the Right Way to Measure Harmful Interference? Assess whether the GPS Device Able to Function. (cont.)

- NASCTN KPIs:
  - "After screening the proposal and initiating this project, NASCTN convened a panel of technical experts to develop a test plan with these following objectives:
    - → develop a test plan that is transparent, reproducible, and well-calibrated,
    - → develop sound, statistically-valid data retrieval and processing techniques,
    - → provide a clear path from measurement setup, to data collection, to processed results, and
    - → provide data to inform discussions between different interested parties on proper measurement requirements."
  - "The test method was designed to make reproducible measurements under clearly-defined test conditions in order to isolate impacts of radiated LTE signals on GPS receivers, and to allow others to make comparable measurements if desired. To accomplish this, the approach aimed to measure the response of selected GPS devices given well-controlled GPS and LTE power levels under fixed, stable thermal noise conditions, while limiting the number of other extraneous variables."
  - "In order to support a broad understanding of GPS receiver performance, the test plan focused on a variety of measurands, including carrier-to-noise-density ratio (C/N_0), 3D position error (3DPE), timing error, number of satellites in view, time to first fix (TTFF), and time to first reacquisition (TTFR). The tests assessed each of these measurands across a large range of adjacent-band LTE power levels." (Exec. Summary p. vii)

Why 1dB C/N_0 Is Not the Proper Metric

1 dB C/N_0 is not measured accurately or consistently because it is not a defined standard

- The data shows that 1 dB C/N_0 is entirely unreliable as an indicator of anything. Every study shows that GPS devices report different changes in C/N_0 when faced with the identical RF spectrum environment, and that different devices by the same manufacturer report different changes in C/N_0. The data establishes that 1 dB C/N_0 is an unpredictable, unrepeatable measurement. As a result, it could simply never be "a standard" and it is misleading to suggest otherwise. *See* Appendix D at 46-50 (NASCTN Report at 146, Fig. 6.25; id. at 126, Fig. 6.5; id. at 131, Fig. 6.10; *see also Order* ¶ 53 n.203 (citing these charts as "demonstrat[ing] the variability in the accuracy of the C/N_0 estimator).
- Some devices measure C/N_0 in 0.5 dB or 0.1 dB and then round up to the nearest whole dB – 1 dB

1 dB C/N_0 cannot be applied as suggested

- 1 dB C/N_0 has been accepted as a standard for measuring the harm caused to a receiver by a transmitter operating in the same band (co-channel operations); it cannot be applied to measure harm caused to a receiver by a transmitter operating in a different band (adjacent band operations)
- The FCC Order affords 1 dB C/N_0 level protection for all GPS devices operating in the GNSS band

1 dB C/N_0 does not indicate harmful interference

- The data shows that a 1 dB C/N_0 decrease in reported C/N_0 does not correlate with a change in the ability of a GPS device to report accurate location or timing information. Impact on device functionality is the true and accepted measure of harmful interference.
    - The DOT acknowledged that it was not measuring harmful interference in its ABC Study

1 dB C/N_0 is not stable, reliable, or justifiable

- The data shows that a GPS device's reported C/N_0 fluctuates all the time, by a range of several dB, even in the absence of any terrestrial transmissions or any noise at all (i.e., in an anechoic chamber!). As Mark Sturza, a well-respected spectrum expert, explained : "If GPS/GNSS receivers became unpredictable when experiencing a 1 dB drop in C/N_0 (or equivalently 25% higher $N_0 + I_0$ level), there would be no GPS industry because fluctuations of 1 dB in C/N_0 happen so frequently with GPS devices that they are simply assumed as a given."

Why 1dB C/N_0 Is Not the Proper Metric (cont.)

1 dB would stall innovation

- If the FCC were to apply 1 dB to all bands adjacent to GPS, then many existing wireless systems in operation today would have to be shut down. Those affected systems would include Iridium's Certus system and AWS-3 Uplink bands—both of which already exceed the 1 dB noise floor—as well as spectrum bands under study by NTIA for future use like 1300-1350 MHz

USG Stakeholders were all aware that 1 dB C/N_0 was not an accepted standard

- The DOT ABC Study did not evaluate any metric other than 1 dB even though it was aware that neither the NTIA nor the FCC found it to be legally relevant or technically sound
- DOD had urged the DOT to use a different metric, but the DOT persisted.

The agreements between Ligado and the GPS companies support the conclusion that 1 dB C/N_0 is not the proper metric of harm for adjacent band operations

- The major GPS companies confirmed in the co-existence agreements that their devices could co-exist with Ligado's operations at a power level of 32 dBW—a power level 99.4% higher than that approved in the Order (9.8 dBW).
  - For example, Garmin stated that it "agreed not to oppose the Ligado Modification applications precisely because, speaking only for [its] devices, the technical parameters to which it agreed in [its] Settlement Agreement were based on its own testing using the 1 dB Standard." Comments of Garmin International, Inc., IB Docket No. 12-340, at 10 (July 9, 2018).
- Because all the GPS companies that filed in the Ligado proceeding entered into co-existence agreements with Ligado, there are only two logical conclusions: (1) Ligado meets the 1 dB C/N_0 standard (as Garmin acknowledged that it does), even at 32 dBW; or (2) the 1 dB metric has never been a relevant metric for the GPS companies or their devices. To suggest otherwise—that the GPS companies could coexist at 32 dBW notwithstanding 1 dB C/N_0, but not at 9.8 dBW—is paradoxical.

The FCC's Assessment of Harmful Interference and Testing

- The Order reviews three tests that examined potential interference concerns relating to Ligado's proposed terrestrial operations and GPS:
  - The Roberson and Associates Reports (RAA Reports)
  - The National Advanced Spectrum and Communications Test Network Report (NASCTN Report)
  - The DOT Adjacent Band Compatibility Assessment Final Report (DOT ABC Report)
- The FCC explains that the test employ two different approaches, only one of which is consistent with the FCC's harmful interference standard: (¶48)
  - One approach – used by the RAA Reports and the NASCTN Report – uses performance-based metrics and evaluated whether Ligado's proposal would impact GPS operations. (¶48)
  - The other approach – used by DOT ABC Report and the only data relied on by DOD – used an interference protection criterion known as 1 dB C/N_0. (¶48)
    - The FCC stated that the 1 dB C/N_0 does not assess whether the actual performance of the GPS devices is affected, and accordingly does not directly address whether there would be any "harmful interference" to GPS. (¶48)
    - The FCC stated that there are technical and policy reasons not to adopt 1 dB C/N_0: (¶48)
      - It is unreliable: the C/N_0 estimators are not capable of accurately and reliably discerning a 1 dB change in the C/N_0 (¶59)
        - For example, the GPS Interface Specification, published by the GPS Directorate, indicates to users of the GPS Space Segment that they could expect a variation in the C/N_0 of approximately 2 dB due to the movement of the polar-orbiting GPS satellites across the field-of-view of a GPS receiver. (¶52)
      - It leads to bad policy: relying on interference protections based on the worst performing receivers (as the DOT ABC Report's application of the 1 db C/N_0 metric does) would undermine the FCC's ability to promote efficient use of its spectrum resources and achieve spectrum management goals. (¶57)
- Here are the FCC Order's conclusions regarding the RAA Report, the NASCTN Report, and the DOT ABC Report
  - The FCC concludes that its evaluation of the receiver test data presented in the record will rely on performance-based metrics, and not on testing based on application of the 1 dB C/N_0 degradation as a measurand, as this does not assess and is not directly correlated with harmful interference. (¶47)
  - The FCC found "that there are important deficiencies in the DOT ABC report." It involved a technically flawed methodology which made its data unreliable and the results were based solely on the worst performing GPS receivers. (¶ ¶ 54, 55, 57)

The ITU Does Not Support the Assertion that 1 dB C/N_0 is the Established Standard for Measuring Harm from Adjacent Band Operations

Ligado has long agreed that a 1 dB C/N_0 change is a reasonable guideline for cochannel (in-band) emissions (i.e., emissions into the GNSS band). But neither the Commission nor the ITU has ever used a standard of 1 dB C/N_0 degradation to protect a service from transmissions in an adjacent band, which is the situation the License Modification Applications raise. The table below identifies nearly a dozen ITU technical papers and recommendations on how spectrum policymakers should manage interference; none of them even propose a standard of 1 dB C/N_0 for adjacent band operations.

ITU-R M.1460-1, Technical and operational characteristics and protection criteria of radiodetermination radars in the frequency band 2 900–3 100 MHz, https://www.itu.int/rec/R-REC-M.1460/en	ITU-R M.1739-0, Protection criteria for wireless access systems, including radio local area networks, operating in the mobile service in accordance with Resolution 229 (WRC-03) in the bands 5 150–5 250 MHz, 5 250–5 350 MHz and 5 470–5 725 MHz, https://www.itu.int/rec/R-REC-M.1739/en
ITU-R M.1461-1, Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services, https://www.itu.int/rec/R-REC-M.1461/en ITU-R M.1462-0	ITU-R M.1800-0, Protection of the fixed, mobile and radiolocation services from MSS feeder links that may operate in the bands 1 390–1 392 MHz (Earth-to-space) and 1 430–1 432 MHz (space-to-Earth), https://www.itu.int/rec/R-REC-M.1800/en
ITU-R M.1462-0, Characteristics of and protection criteria for radars operating in the radiolocation service in the frequency range 420–450 MHz, https://www.itu.int/rec/R-REC-M.1462/en	ITU-R M.1903-0, Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) and receivers in the aeronautical radionavigation service operating in the band 1 559–1 610 MHz, https://www.itu.int/rec/R-REC-M.1s903/en
ITU-R M.1463-2, Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215–1 400 MHz, https://www.itu.int/rec/R-REC-M.1463/en	ITU-R M.1904-0, Characteristics, performance requirements and protection criteria for receiving stations of the radionavigation-satellite service (space-to-space) operating in the frequency bands 1 164–1 215 MHz, 1 215–1 300 MHz and 1 559–1 610 MHz, https://www.itu.int/rec/R-REC-M.1904/en
ITU-R M.1465-1, Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency range 3 100–3 700 MHz, https://www.itu.int/rec/R-REC-M.1465/en	

NASCTN Study Found 1 dB C/N_0 Is an Inaccurate and Unreliable Measure of Harmful Interference

- The NASCTN Study was performed at the request of the DOD CIO
- About NASCTN
  - In 2015, NIST, NTIA, and DOD jointly established the National Advanced Spectrum and Communications Test Network (NASCTN) to "improve opportunities for successful spectrum sharing through accurate, reliable, rigorously scientific, and unbiased measurements and analyses via a voluntary, cooperative federated network of spectrum sharing expertise and capabilities." (About NASCTN; NASCTN charter)
  - On February 15, 2017, NASCTN released its scientifically repeatable study on whether Ligado's proposed network deployment would impact GPS receivers on February 15, 2017. This study – which won the Department of Commerce Gold Medal for distinguished and exceptional scientific and engineering achievement and was based on thousands of hours of device testing– found that Ligado's proposed network can co-exist with GPS receivers.
- As for 1 dB C/N_0, the NASCTN testing revealed
  - There is no standardized method to measure and report C/N_0
  - Device-reported C/N_0 varies by more than 1 dB in good signal conditions
  - Device-reported C/N_0 for the same interference varies from device to device; and
  - Most significantly, there is no correlation between GPS device function experienced by the user (i.e., position error) and 1 dB C/N_0 change for a wide variety of devices
- NASCTN study design (differences between NASCTN and DOT)
  - "To better understand the potential impact of adjacent-band LTE signals on GPS receiver performance, NASCTN developed a draft test plan designed to measure how the performance of GPS receivers changed as a function of increasing LTE signal power relative to a baseline with no LTE emissions." (Press Release, NASCTN Releases Report on LTE Impact on GPS Receivers)
  - "In total, NASCTN performed 1,476 hours of testing and collected over 19,000 data files for a variety of measurands that were collected from a number of GPS devices. These data were collected at a baseline condition (no LTE signals present) and over a large range of LTE signal power levels. Subsequent data processing yielded a set of 3,859 anonymized data files (780 MB) that is available along with the NASCTN report."

Important Facts About the DOT Adjacent Band Compatibility Study

- Study design was part of the reason the study is not reliable:
  - The DOT studied only Ligado's proposed operations and did not assess the impact of other L-Band operators on GPS
  - The DOT Report is based on incorrect technical parameters and not on the technical parameters Ligado actually proposed
  - The DOT tested all 80 Devices Under Test at the same time and in the same semi-anechoic chamber in close proximity to one another which created unquantifiable measurement uncertainties
  - The testing itself took one week to complete but the test process took six years
  - The FCC discussed these flaws at length in Paragraph 54 of the Order
- The DOT ABC study developed a recommended Interference Tolerance Mask (ITM) for spectrum bands adjacent to GNSS (including L1 band signals); it did not purport to study harm or harmful interference
  - The mask purported to show the safe power level for operations in bands adjacent to the GNSS band
- The ITM is based entirely on a 1dB change in C/N_0 and does not account for any other metric; the mask does not account for device performance
- The ITM was developed based solely on the results of the worst-performing receiver, but the DOT:
  - Did not consider the use case/user of that worst-performing device
  - Did not consider the number of those worst-performing devices in use or how old the device is
  - Did not consider whether the device was operating in the GNSS band or in Ligado's band (was the device entitled to any protection where it was operating?)
- The DOT did not make their data publicly available
  - The DOT also did not make the device specifications available

TAKEAWAYS AND NEXT STEPS

Takeaways

- The FCC process was robust, fair, data driven and transparent
- The FCC Order protects GPS from harmful interference
- Ligado is committed to its obligations to protect GPS
- Ligado and its technology partners are ready and willing to deliver innovative 5G technologies

Next Steps

- Ligado looks forward to continuing to engage with the NASEM Committee
- In the meantime, Ligado will continue to try to talk with the DOD and other agencies to exchange information for the repair and replace program

Appendix A - Timeline

Timeline

1989	FCC granted L-Band satellite license to Ligado's predecessor company.
2001	Ligado's predecessor company first proposed using its licensed L-Band satellite spectrum for a terrestrial network.
2002	Following discussions with GPS industry representatives, the company and the U.S. GPS Industry Council (USGIC) agreed to curtail any portion of the company's signal that crossed into GPS frequencies (OOBE).
2003	The FCC adopted initial rules allowing the company's ground network to operate in bands adjacent to GPS; these rules were adopted pursuant to the FCC's standard processes, which included a full review by DOD, FAA, and all other interested government agencies.
2004	The FCC authorized the company to deploy an integrated satellite-terrestrial network, consistent with the 2003 Order.
2010	The company requested a handset waiver to confirm that the company was allowed to meet its mandate of providing mobile broadband access to 260 million Americans using a mix of dual and single-mode handsets. The waiver application did not change the power, number, deployment, or any other technical characteristic of the company's base stations. The parameters were established between 2003 and 2005 under the FCC's standard processes.
2011	The FCC granted the waiver conditionally, after USGIC raised concerns that any kind of terrestrial network in the company's already-authorized licensed spectrum would harmfully interfere with the operation of GPS devices.

Timeline

2011	National Academies of Sciences, Engineering and Medicine report on Telecommunications Research at the Department of Commerce noted that "during the National Executive Council on Space-Positioning, Navigation and Timing deliberations on the company LightSquared in 2011, then Deputy Secretary of Defense Ashton Carter and Deputy Secretary of Transportation John Porcari affirmed the need for an independent and impartial organization, environment, and process for testing and evaluating new spectrum-sharing technologies to support policy decisions. Momentum built in 2012 with the publication of the President's Council of Advisors on Science and Technology (PCAST) report Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth and a 2013 Presidential memorandum directing NIST and NTIA to establish a plan to accelerate the development and deployment of spectrum-sharing technologies. The NASCTN transition team consisting of NIST, NTIA, and DOD staff was established in Boulder, Colorado, in 2013. The NTIA director, NIST director, and DOD chief information officer signed a memorandum of agreement (MOA) establishing NASCTN on March 11, 2015. Although a part of the formation of the organization as noted above, at the time of this report, the Department of Transportation has not joined this group. NASCTN was established to increase commercial and federal access to the spectrum by helping to accelerate the design and deployment of spectrum-sharing technologies through accurate testing and modeling. The intent is to create an environment of trust to support impartial testing and evaluation of new spectrum sharing technologies and, ultimately, balanced policy decisions that are driven by scientifically sound tests and evaluations. NASCTN is structured as a one-stop shop for coordinating access to federally owned, federally operated, or federally funded spectrum test facilities. NASCTN is meant to enable sound policy decisions based on effectively engineered sharing solutions produced by member laboratories."
2012	NTIA sent a letter to the FCC stating that it has concluded that the company’s proposed broadband network will impact GPS services and “that there is no practical way to mitigate the potential interference at this time.”
2012	FCC issued a Public Notice in February asking for comments on whether they should vacate their January 2011 Conditional Waiver Order and suspend indefinitely the previously-granted authority the agency had given to deploy terrestrial operations. Ligado's predecessor company filed for Chapter 11 reorganization in May 2012.

Timeline

2012	The President's Council of Advisors on Science and Technology (PCAST) released a report in August, "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth." Included "Box 3.1: The LightSquared (predecessor company)–GPS Controversy: An Illustration of the Need for Receiver Management."
2012	DOT and FAA completed a draft of their project plan for the Adjacent Band Compatibility (ABC) Study; it was not publicly released for another 2 years.
2013	The Department of Commerce, the Department of the Air Force, Department of the Army, Department of the Navy, and the National Aeronautical and Space Administration submitted a memorandum to the Interdepartmental Radio Advisory Committee (IRAC) Chairman stating that "the DOD, Army, Navy, Air Force, and undersigned Federal Agencies do not object at this time to the analysis of LightSquared's uplink frequencies as proposed by LightSquared in its license modification proposal filed with the FCC on September 28, 2012."
2013	DOD CIO Principal Director Christine Condon emailed the chief of staff of a senior member of Congress in October that DOD has "no issue with approving the [Ligado] proposal and asks the IRAC to tell the FCC we approve." This was specifically with respect to the bands at 1627.5- 1637.5 MHz and 1646.5-1656.5 MHz (the so-called "handset spectrum").
2014	A Communications Daily article noted a DOD CIO official stated that Ligado's OOBE limit was adequate. "Due to its close proximity to the GPS band, LightSquared voluntarily accepted a more restricted OOBE limit of -95 dBw/MHz," said Geoff Stearn, vice president-spectrum development at LightSquared. "They seem to be adequate," said James Campion, principal action officer, office of the DOD Chief Information Officer
2014	NTIA Associate Administrator Karl Nebbia sent a letter to FCC Chief of Engineering and Technology Julius Knapp re: uplinks; included Sept. 18, 2013 letter from DOT Deputy Secretary John Porcari. While sharing DOT opposition with the FCC, the letter notably lacked the mention of any DOD opposition to Ligado's proposal to use the uplinks.
2015	Ligado (Doug Smith, Reed Hundt, Ashley Durmer, Gerry Waldron, Dennis Roberson) met with DOD officials Fred Moorefield, Raymond J. Swider, James Campion, Kenneth Turner.
2015	NTIA, NIST, and DOD-CIO signed a memorandum of agreement (MOA) in March to establish the National Advanced Spectrum and Communications Test Network (NASCTN); signed by Larry Strickling (NTIA), Willie E. May (Acting NIST Director), and Terry A. Halvorsen (Acting DOD CIO). (*See* 2011 National Academies report re: NASCTN above)

Timeline

2015	The company reached settlement agreements (“Co-existence Agreements”) in December with GPS companies Deere and Garmin. “Garmin spokeswoman Carly Hysell said [Ligado’s] agreement to cut out-of-band emissions and power levels in the spectrum band closest to the GPS signal protects the interests of GPS users, and the company doesn’t anticipate any performance-degradation issues for those using GPS technologies.” (Wall Street Journal, December 17, 2015)
2015	The company filed its License Modification Applications (Applications) in December based on specifications in GPS co-existence agreements.
2016	USAF GPS Directorate conducted “classified” testing of military GPS receivers.
2016	FCC issued Public Notice on Applications and solicited public comments in April.
2016	For its DOT ABC study, DOT tested GPS/GNSS receivers at US Army Research Laboratory’s Electromagnetic Vulnerability Assessment Facility at the White Sands Missile Range facility in New Mexico with 80 civil GPS and GNSS receivers. Participation included USCG, NASA, NOAA, USGS, FAA, and GPS manufacturers.
2016	Roberson and Associates test results and analysis were submitted to the FCC.
2016	Ligado and high-precision GPS device manufacturer and DOD supplier NovAtel filed a letter in June with the FCC noting they had recently reached a co-existence agreement. “We are pleased to report that after considerable discussion and analysis [NovAtel and Ligado] have reached a co-existence agreement which calls for future coordination… On the basis of this understanding, NovAtel supports Commission granting of the modification applications.”
2017	Passage of FY2017 NDAA repealed previous FY2012 NDAA language; the repeal language recognized the FCC’s authority and expertise in making spectrum decisions relating to appropriate GPS frequency protections. In short, that law affirmed the clear statement in the Communications Act: the FCC is exclusively charged with resolving issues regarding GPS and spectrum allocation. This repeal resulted from collaboration which included classified briefings and a thorough vetting among leadership of the House; the HASC; the House Energy & Commerce Committee (E&C); and officials with DOD and the FCC.

Timeline

2017	The National Advanced Spectrum and Communications Test Network (NASCTN), which is administered with the oversight of DOD and the Commerce Department, released test results from its study showing that Ligado's operations would not cause harmful interference. The testing was performed at the specific request of DOD's Fred Moorefield, with the DOD's Chief Information Office and DOD contractors participating in the testing. NOTE: NASCTN won a Department of Commerce Gold Medal Award in 2017 for the breakthrough testing.
2017	DOT held its sixth ABC Study workshop.
2017	The DOD took the lead in resolving the Iridium/Ligado commercial dispute by proposing an independent, third-party, Alion Science, conduct a study. After months of testing, in August, Alion reported back to DOD that Ligado's proposed ATC terminals would not cause harmful interference to Iridium's MSS terminals. Ultimately, the FCC agreed in its April 2020 Ligado Order and explained that maintaining OOBE within limits consistent with the standard included in the 2003 Ancillary Terrestrial Component (ATC) Order would avoid the possibility of causing interference to Iridium.
2018	DOT released its Adjacent Band Compatibility Assessment (DOT ABC Report).
2019	In October, the FCC shared a draft Order approving Ligado's applications with federal agencies, including Department of Defense, Department of Homeland Security, NASA, Department of Commerce, Department of Transportation, FAA, Department of Justice, Department of State, Department of Energy, USDA, Department of the Interior, and Department of Treasury. Per FCC Chairman Ajit Pai's letter to several Senators: "In the typical situation, the IRAC process provides for a three-week period for feedback. But in order to give federal agencies more time to formulate comments on the FCC's draft decision, the Commission agreed to extend that three-week period for an additional month. After receiving input from federal agencies in December 2019, when the Department of Defense informed the Commission that it had additional information to submit for the public record, the FCC paused further work on the application until March so that the Department would have yet another opportunity to share its views with the Commission. Although NTIA did supply additional information from the Department of Defense in April 2020 (a February 2020 Air Force memorandum), it did not supply any additional technical analysis for the Commission's consideration."

Timeline

2019	Communications Daily article reported on emails from 2015 between DOD officials discussing the necessity of the 1 dB C/N_0 metric. In an email to a PNT official, a senior DOD CIO official said they were "very concerned that bunkering down with this criteria as the only thing we are willing to explore or verify is a losing proposition, especially since we have both NTIA and FCC not supporting. We have to do our due diligence and explore other options and if we ultimately come back to this criteria as the best way to protect GPS then so be it. But to say we will not explore other options because in the past it was supported is not a good strategy." The email argues DOD must be "much more strategic in how we go about doing this."
2020	FCC issued a unanimous Order approving Ligado's ATC operations after 17 years of study, debate and analysis.
2020	DOD CIO official sent email to Ligado leadership regarding the FCC Ligado Order in April; the email included details of DOD deliberations, actions and positions since 2005 and noted that "DOD GPS by doctrine and design operates majorly on its own military L2 signal far, far away at 1227 MHz, and also but only in minor part with the other civil L1 C/A signal far enough away at 1575 MHz. The DOD and US Military have not significantly relied upon the legacy GPS L1 signal at 1559 MHz for years; in now starkly obvious retrospect the DOD most probably never have waged any federal regulatory battles over the Ligado matters, certainly not since 2015 or 2016, and as I forecast so many times to DOD leaders the FCC has finally, deservedly, unanimously publicly repudiated them." The official within the CIO's office also pointed out, "Since 2015 when all of the major commercial GPS receiver manufacturers filed to the FCC that their GPS operations could accommodate the revised Ligado proposal, and soon after in 2016 when I witnessed the Air Force's weak weeklong testing at White Sands Missile Range, I repeatedly and incrementally advised DOD leaders of the inexorable writing on the wall towards a likely ultimate FCC determination as yesterday or comparable. During the entire calendar year of 2017, I was the DOD lead within the NTIA and FCC supervised All Agency Tech Focus Group that comprehensively analyzed all of the existing data to that date."
2020	NTIA filed Petitions for Stay and Reconsideration in Ligado proceedings.
2020	Rep. Cathy McMorris Rogers (R-WA), Ranking Member of the House Energy and Commerce Committee, released a statement in opposition to the inclusion of the language singling out Ligado in the FY 2021 NDAA. "The NDAA shouldn't target an American company that will hurt our ability to beat China in the 5G race. Why single out an American company focused on boosting our country's 5G leadership but leave out protections against Chinese drone manufacturers threatening our national security? This should be made right."

Timeline

2021	FY2021 NDAA became law following the congressional override of presidential veto. FY2021 NDAA includes language asking the National Academies of Sciences, Engineering, and Medicine to provide an independent technical review of the FCC Ligado Order.
2021	FCC issued its Order denying the NTIA Motion for Stay to its unanimous, bipartisan April 2020 Ligado Order.

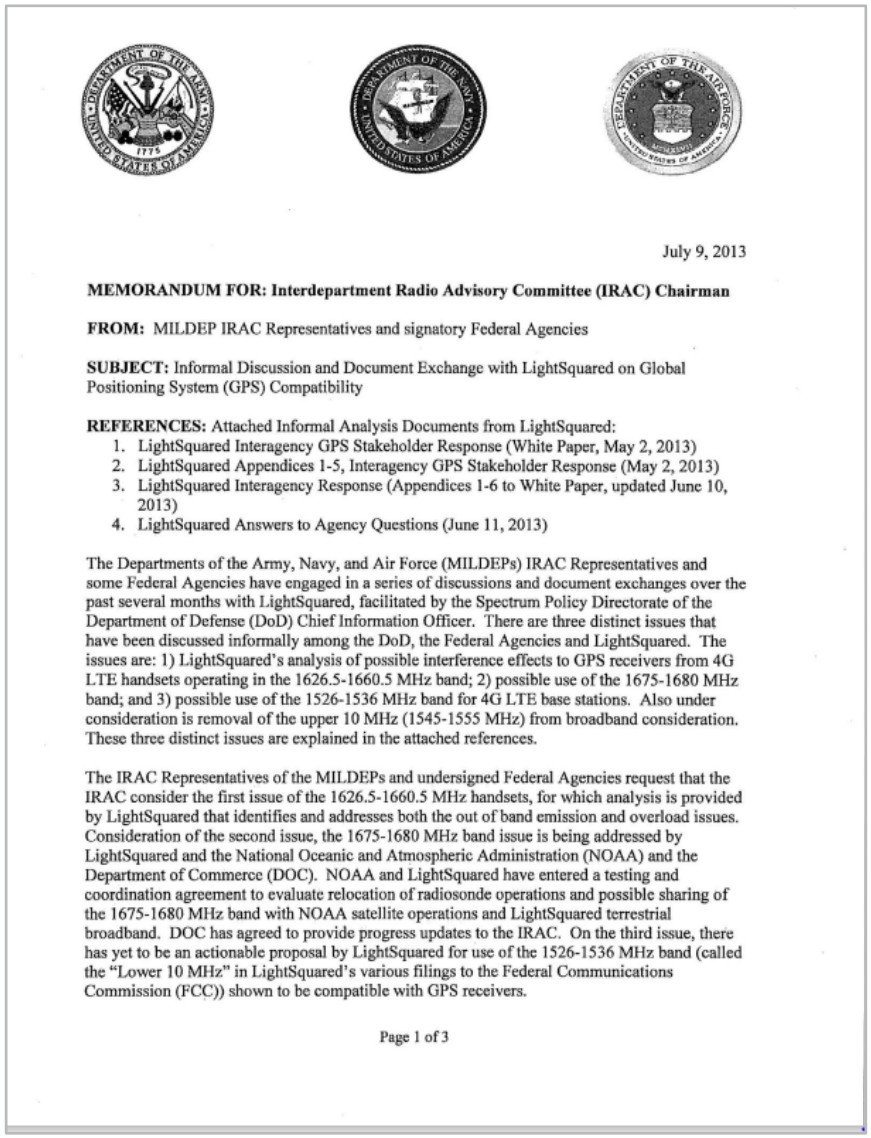
Appendix B - 2012 NTIA Letter and Ligado's Response

In 2012, the NTIA Laid Out a Road Map to Resolution of Legitimate GPS Concerns, That Road Map Led to Ligado's 2015 Proposal and the FCC Order

2012 NTIA Proposal	Action Taken	Status
Modify operating parameters to reduce impacts on GPS receivers to an acceptable level	• Ligado modified its operating parameters to satisfy GPS industry that co-existence would not harm GPS	✓
GPS receivers used in cellular and personal/general navigation GPS receivers can be designed to be compatible with the lower 10 MHz base station signal and deployed over time without disrupting user requirements.	• Ligado worked directly with GPS companies to ensure receiver co-existence with Ligado's network • Resilient receivers are available in the market today	✓
NTIA to request FAA update standards	• Ligado worked with the FAA to develop a plan to protect all certified aviation devices; Ligado's proposal protects safety of life applications	✓
NTIA to lead review of receiver requirements	• Ligado worked directly with GPS companies to ensure receiver co-existence with Ligado's network	✓
NTIA to urge FCC to mitigate GPS receiver impact on full spectrum utilization	• Ligado worked directly with GPS companies to ensure receiver co-existence with Ligado's network	✓
PNT EXCOM to develop and establish new GPS interference standards that strike a balance between interference caused by transmitters and the performance of GPS receivers	• Ligado worked directly with GPS companies to ensure receiver co-existence with Ligado's network • 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	✓

Appendix C - 2013 IRAC Memo

2013 IRAC Memo (Page 1 of 3)



July 9, 2013

MEMORANDUM FOR: Interdepartment Radio Advisory Committee (IRAC) Chairman

FROM: MILDEP IRAC Representatives and signatory Federal Agencies

SUBJECT: Informal Discussion and Document Exchange with LightSquared on Global Positioning System (GPS) Compatibility

REFERENCES: Attached Informal Analysis Documents from LightSquared:

1. LightSquared Interagency GPS Stakeholder Response (White Paper, May 2, 2013)
2. LightSquared Appendices 1-5, Interagency GPS Stakeholder Response (May 2, 2013)
3. LightSquared Interagency Response (Appendices 1-6 to White Paper, updated June 10, 2013)
4. LightSquared Answers to Agency Questions (June 11, 2013)

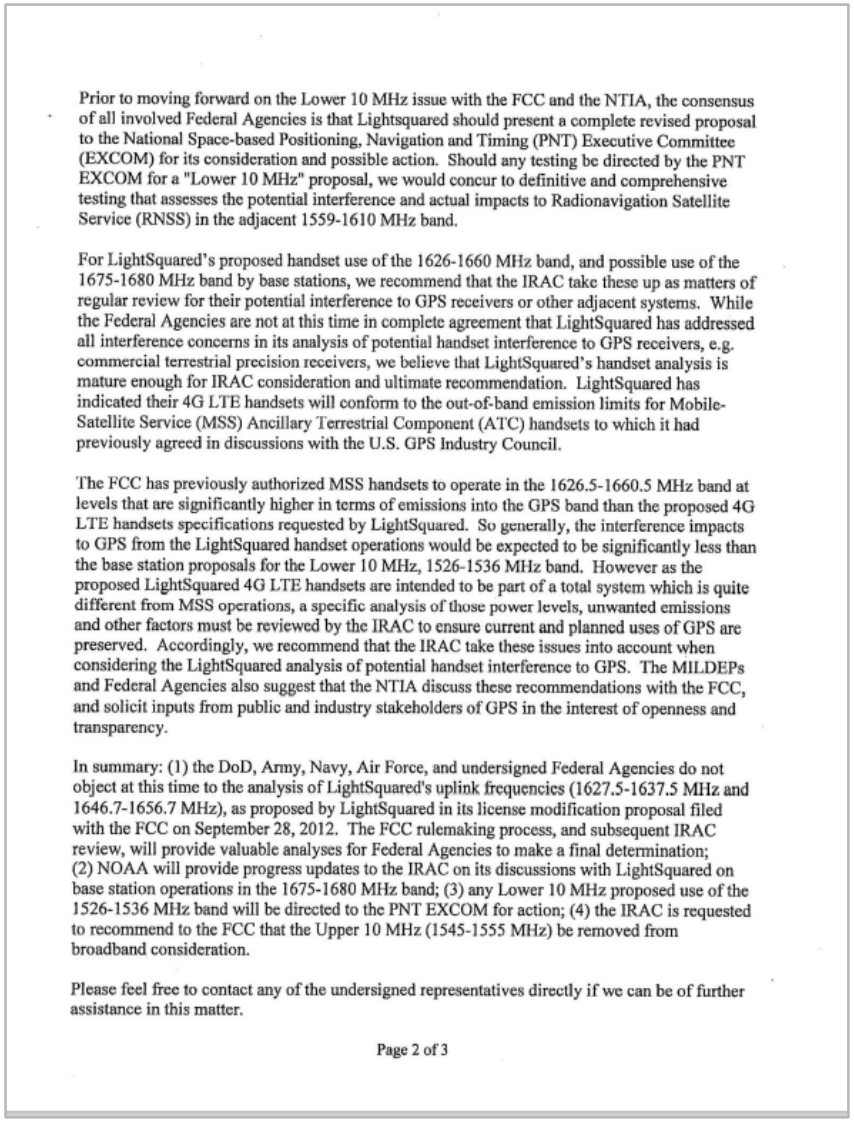
The Departments of the Army, Navy, and Air Force (MILDEPs) IRAC Representatives and some Federal Agencies have engaged in a series of discussions and document exchanges over the past several months with LightSquared, facilitated by the Spectrum Policy Directorate of the Department of Defense (DoD) Chief Information Officer. There are three distinct issues that have been discussed informally among the DoD, the Federal Agencies and LightSquared. The issues are: 1) LightSquared's analysis of possible interference effects to GPS receivers from 4G LTE handsets operating in the 1626.5-1660.5 MHz band; 2) possible use of the 1675-1680 MHz band; and 3) possible use of the 1526-1536 MHz band for 4G LTE base stations. Also under consideration is removal of the upper 10 MHz (1545-1555 MHz) from broadband consideration. These three distinct issues are explained in the attached references.

The IRAC Representatives of the MILDEPs and undersigned Federal Agencies request that the IRAC consider the first issue of the 1626.5-1660.5 MHz handsets, for which analysis is provided by LightSquared that identifies and addresses both the out of band emission and overload issues. Consideration of the second issue, the 1675-1680 MHz band issue is being addressed by LightSquared and the National Oceanic and Atmospheric Administration (NOAA) and the Department of Commerce (DOC). NOAA and LightSquared have entered a testing and coordination agreement to evaluate relocation of radiosonde operations and possible sharing of the 1675-1680 MHz band with NOAA satellite operations and LightSquared terrestrial broadband. DOC has agreed to provide progress updates to the IRAC. On the third issue, there has yet to be an actionable proposal by LightSquared for use of the 1526-1536 MHz band (called the "Lower 10 MHz" in LightSquared's various filings to the Federal Communications Commission (FCC)) shown to be compatible with GPS receivers.

Page 1 of 3

See Ligado FCC Ex Parte, Ex Parte Letter re DoD Memo to IRAC [8.3.2021].pdf (fcc.gov), (August 23, 2021)

2013 IRAC Memo (Page 2 of 3)



Prior to moving forward on the Lower 10 MHz issue with the FCC and the NTIA, the consensus of all involved Federal Agencies is that Lightsquared should present a complete revised proposal to the National Space-based Positioning, Navigation and Timing (PNT) Executive Committee (EXCOM) for its consideration and possible action. Should any testing be directed by the PNT EXCOM for a "Lower 10 MHz" proposal, we would concur to definitive and comprehensive testing that assesses the potential interference and actual impacts to Radionavigation Satellite Service (RNSS) in the adjacent 1559-1610 MHz band.

For LightSquared's proposed handset use of the 1626-1660 MHz band, and possible use of the 1675-1680 MHz band by base stations, we recommend that the IRAC take these up as matters of regular review for their potential interference to GPS receivers or other adjacent systems. While the Federal Agencies are not at this time in complete agreement that LightSquared has addressed all interference concerns in its analysis of potential handset interference to GPS receivers, e.g. commercial terrestrial precision receivers, we believe that LightSquared's handset analysis is mature enough for IRAC consideration and ultimate recommendation. LightSquared has indicated their 4G LTE handsets will conform to the out-of-band emission limits for Mobile-Satellite Service (MSS) Ancillary Terrestrial Component (ATC) handsets to which it had previously agreed in discussions with the U.S. GPS Industry Council.

The FCC has previously authorized MSS handsets to operate in the 1626.5-1660.5 MHz band at levels that are significantly higher in terms of emissions into the GPS band than the proposed 4G LTE handsets specifications requested by LightSquared. So generally, the interference impacts to GPS from the LightSquared handset operations would be expected to be significantly less than the base station proposals for the Lower 10 MHz, 1526-1536 MHz band. However as the proposed LightSquared 4G LTE handsets are intended to be part of a total system which is quite different from MSS operations, a specific analysis of those power levels, unwanted emissions and other factors must be reviewed by the IRAC to ensure current and planned uses of GPS are preserved. Accordingly, we recommend that the IRAC take these issues into account when considering the LightSquared analysis of potential handset interference to GPS. The MILDEPs and Federal Agencies also suggest that the NTIA discuss these recommendations with the FCC, and solicit inputs from public and industry stakeholders of GPS in the interest of openness and transparency.

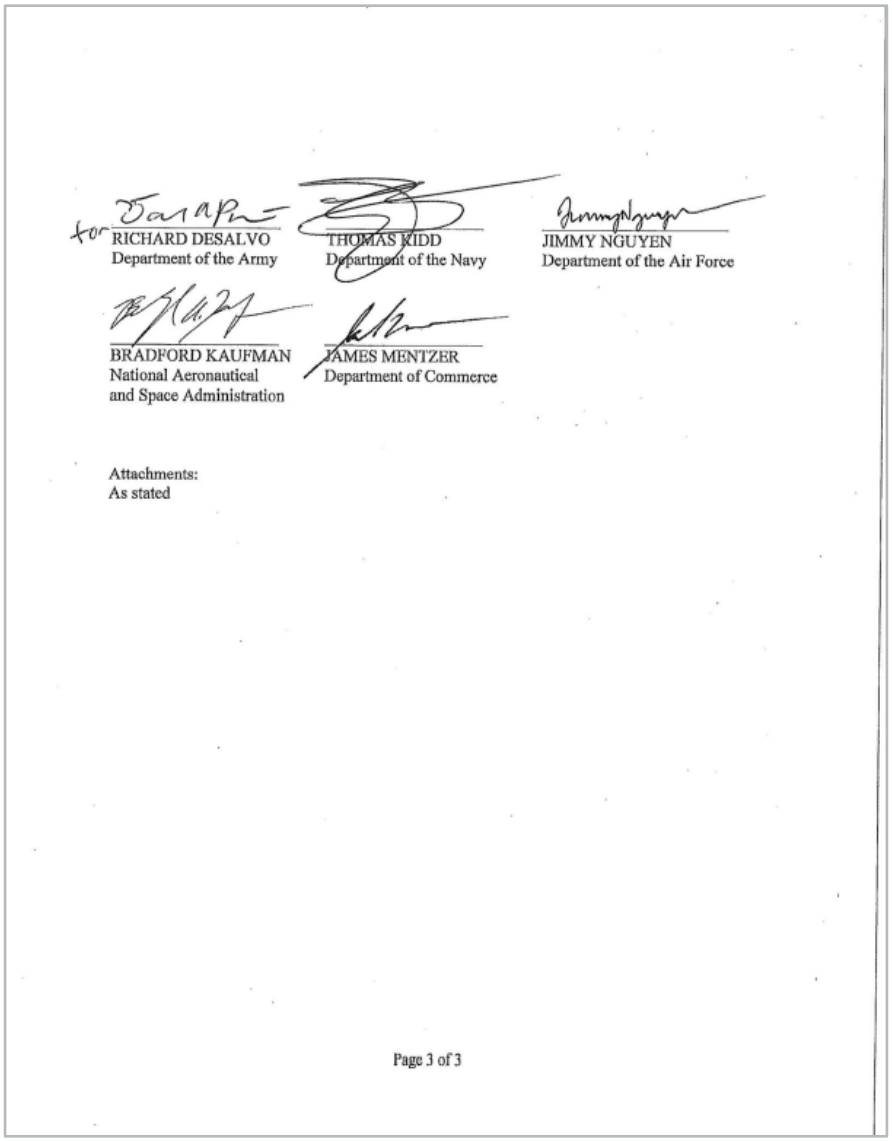
In summary: (1) the DoD, Army, Navy, Air Force, and undersigned Federal Agencies do not object at this time to the analysis of LightSquared's uplink frequencies (1627.5-1637.5 MHz and 1646.7-1656.7 MHz), as proposed by LightSquared in its license modification proposal filed with the FCC on September 28, 2012. The FCC rulemaking process, and subsequent IRAC review, will provide valuable analyses for Federal Agencies to make a final determination; (2) NOAA will provide progress updates to the IRAC on its discussions with LightSquared on base station operations in the 1675-1680 MHz band; (3) any Lower 10 MHz proposed use of the 1526-1536 MHz band will be directed to the PNT EXCOM for action; (4) the IRAC is requested to recommend to the FCC that the Upper 10 MHz (1545-1555 MHz) be removed from broadband consideration.

Please feel free to contact any of the undersigned representatives directly if we can be of further assistance in this matter.

Page 2 of 3

See Ligado FCC Ex Parte, Ex Parte Letter re DoD Memo to IRAC [8.3.2021].pdf (fcc.gov), (August 23, 2021)

2013 IRAC Memo (Page 3 of 3)



for RICHARD DESALVO
Department of the Army

THOMAS KIDD
Department of the Navy

JIMMY NGUYEN
Department of the Air Force

BRADFORD KAUFMAN
National Aeronautical
and Space Administration

JAMES MENTZER
Department of Commerce

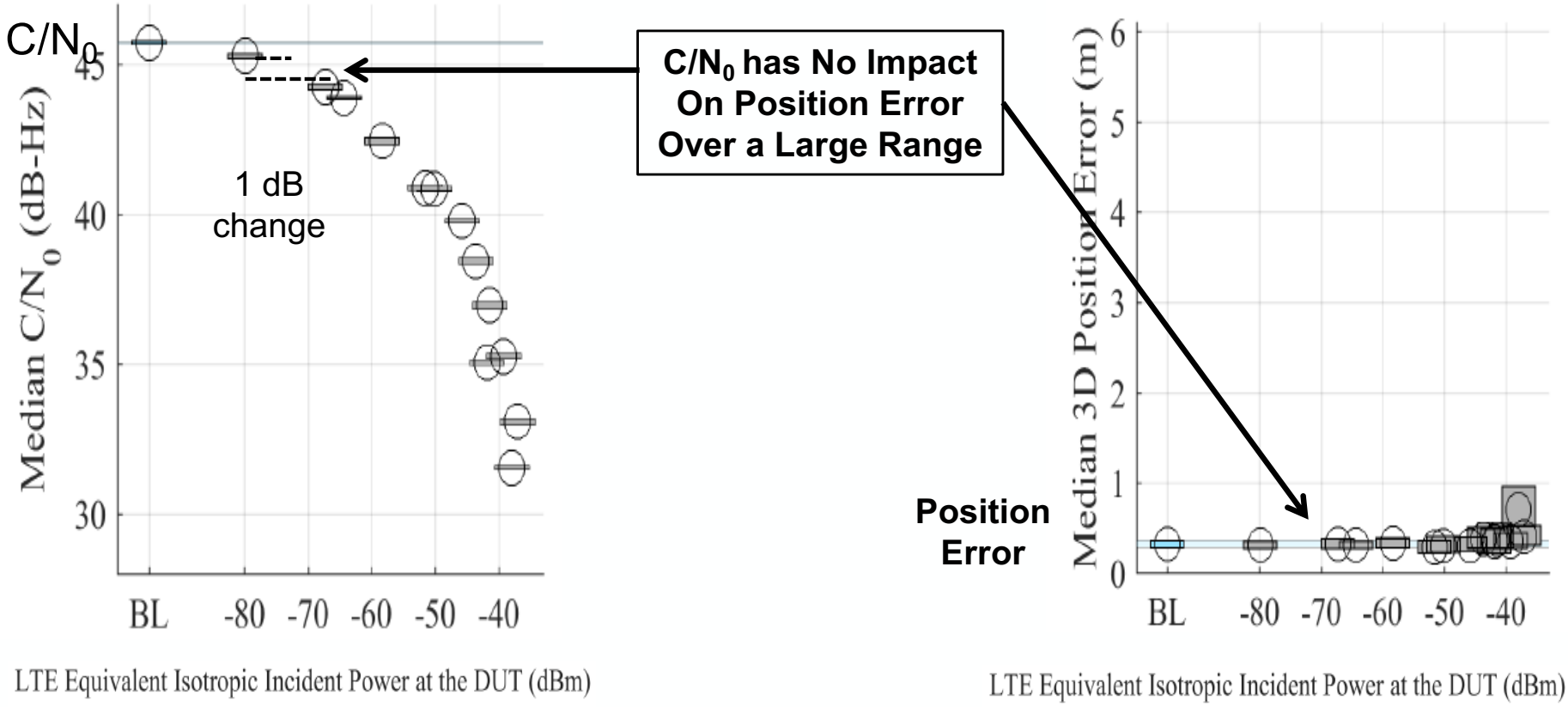
Attachments:
As stated

Page 3 of 3

See Ligado FCC Ex Parte, Ex Parte Letter re DoD Memo to IRAC [8.3.2021].pdf (fcc.gov), (August 23, 2021)

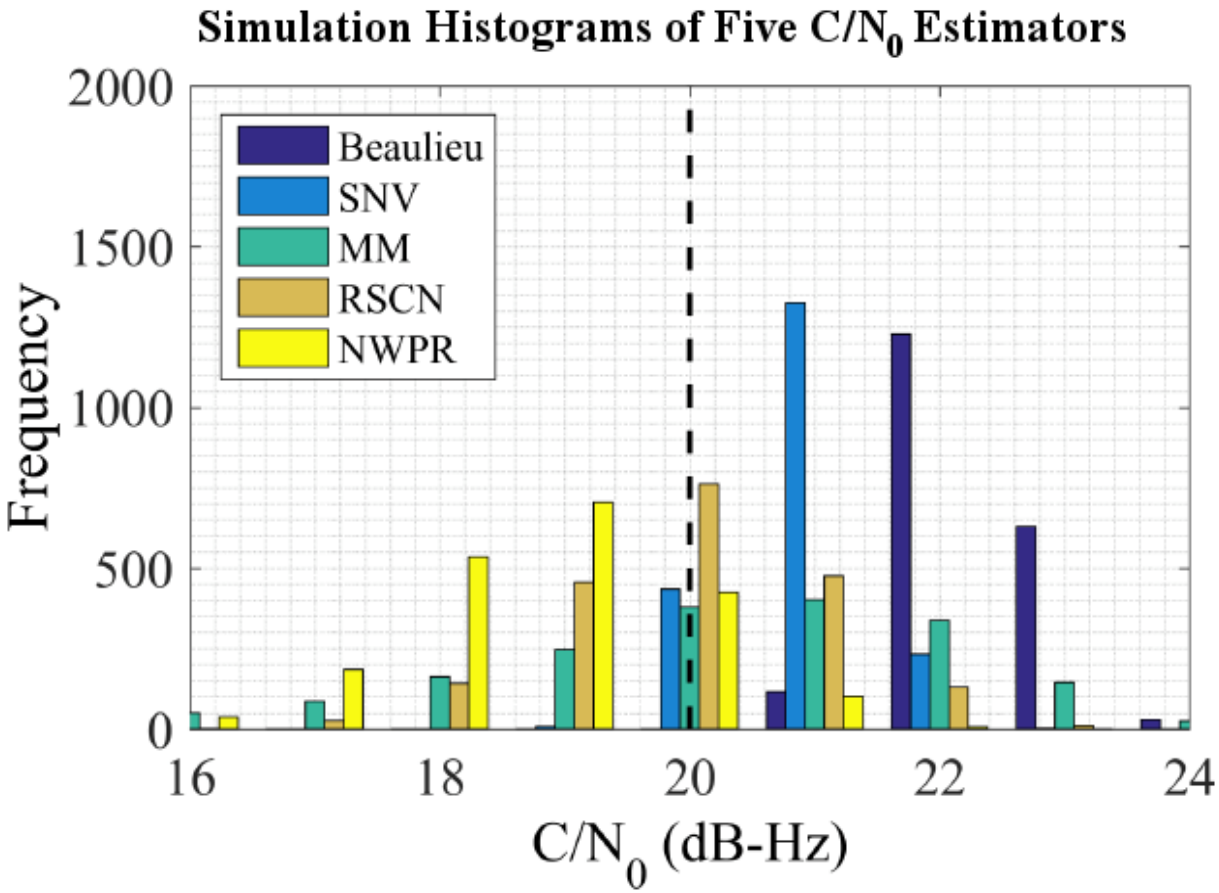
Appendix D – Technical Assessments of 1db C/N_0

NASCTN Study: 1 dB C/N_0 Degradation Does Not Correspond to Impact in User Functionality (Error in Position Reported by Device)*



*From Figures 6.44 and 6.46 of NIST Technical Note 1952 "LTE Impact on GPS"

NASCTN Report C/N_0 Findings



This chart illustrates the results of using five different methods to report C/N_0 for what should be a true 20 dB C/N_0, as indicated by the dotted line. Were 1 dB a precise standardized metric, all five methods should have been able to reflect a true 20 dB measurement with limited or no spread, or at minimum, only one estimation approach should be consistently used by all devices. As abundantly evident from the chart, however, the reported C/N_0 dB estimates instead are all over the map and had an eight-point spread. Such variability reflects the *opposite* of a standardized accurate and reliable measure of interference.

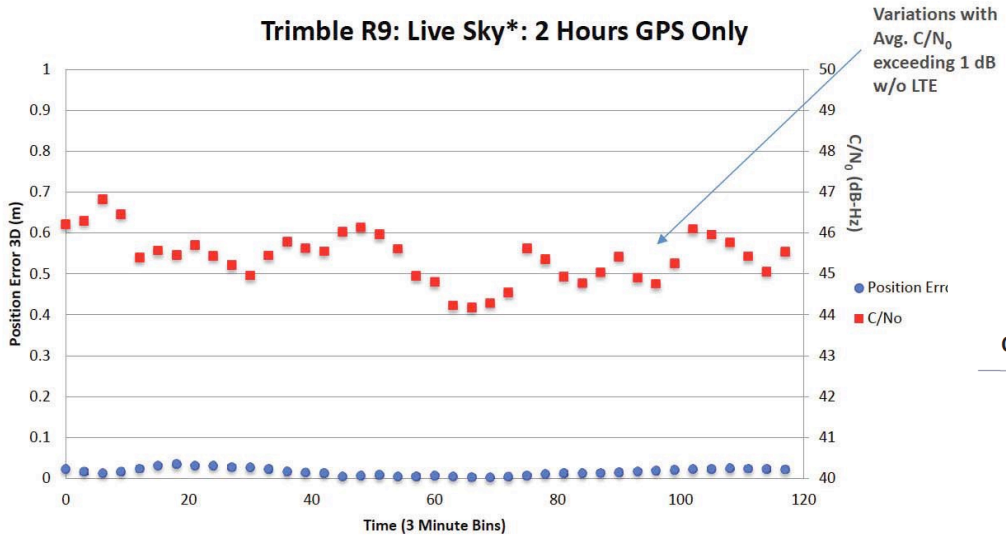
Chart from Dr. William Young et al., NASCTN, LTE Impacts on GPS: Test and Metrology Plan (July 22, 2016), available at https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1952.pdf

Roberson Report 1 dB C/N_0 Findings

1 dB C/N_0 Does Not Accurately Predict Position Error

Roberson and Associates, LLC

Device: TRIMBLE R9 Device Category: HP
GPS Condition: LIVE SKY with RTK
Antenna:
KPI: 3D Position Error, meters (3 Minute Averaging Window)



* For Live Sky, real GPS signals are captured with an antenna and piped into the anechoic chamber

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As illustrated by the red C/N_0 line, the device under testing experienced variations in C/N_0 , with the excursions around the average C/N_0 exceeding 1 dB when averaged over 3 minutes in the absence of any LTE signal. If GPS devices—on their own, absent any LTE signal—can experience a 1 dB change in C/N_0,then a 1 dB change in C/N_0 cannot be an adverse event for the device. Otherwise, GPS devices would be constantly experiencing adverse events.

C/N_0 Does Not Accurately Predict Position Error

Roberson and Associates, LLC

- Average C/N_0 value reported by the receiver (averaged over all GPS satellites) showed small, random variations in absence of adjacent band signals
- Normal variations can exceed 1 dB
- 1 dB degradation in C/N_0 does not accurately predict GPS position performance

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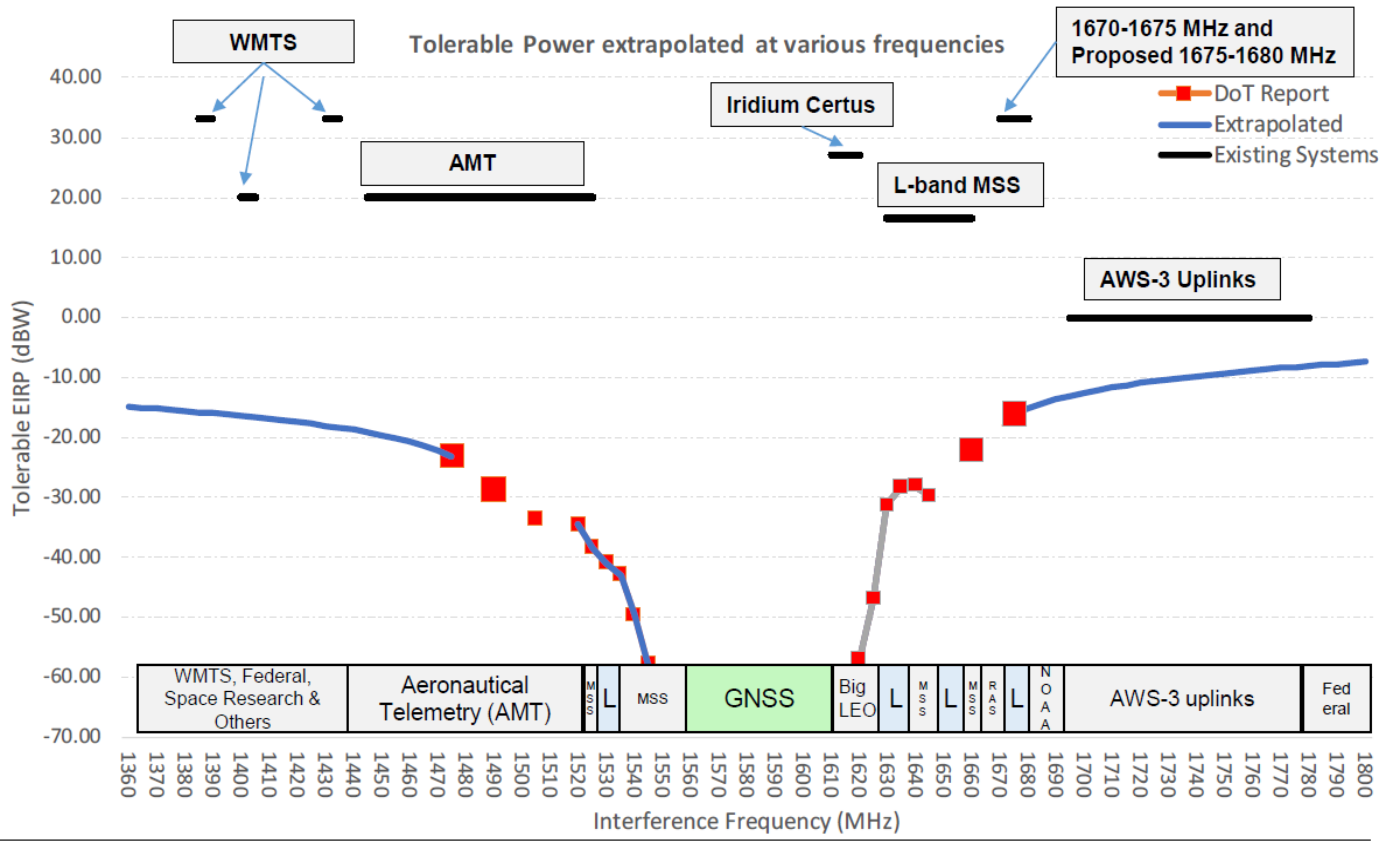
Slides from FCC Ligado Ex-parte filing 2/24/2016 - https://ecfsapi.fcc.gov/file/60001517985.pdf

Roberson Comments On DOT ABC 1 dB C/N_0 Finding Relative To Adjacent Wireless Systems

Tolerable Transmit Power (DoT Report Table 4-6 and 4-8) Extrapolated for GPS L1 C/A

There are many existing systems that exceed 1 dB C/N_0 criteria now



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Slide from FCC Ligado Ex-parte filing 11/25/2019 - https://www.fcc.gov/ecfs/filing/112545361241