Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
LightSquared Technical Working Group Report	)	IB Docket No. 11-109
	)	
LightSquared License Modification Application, IBFS Files Nos. SAT-MOD-20120928-00160, -00161, SES-MOD-20121001-00872	)))	IB Docket No. 12-340
	)	
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PETITION FOR RECONSIDERATION OF TRIMBLE INC.

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Pursuant to Section 1.106 of the Commission's rules,[1/] Trimble Inc. ("Trimble") hereby submits this Petition for Reconsideration of the Commission's *Order and Authorization* in the above-referenced proceedings that granted applications submitted by Ligado Networks LLC ("Ligado") to modify its Mobile Satellite Service ("MSS") authorizations so that it may deploy a nationwide terrestrial wireless network in the 1526-1536 MHz, 1627.5-1637.5 MHz, and 1646.5-1656.5 MHz bands.[2/] Trimble strongly supports the Commission's efforts to foster continued U.S. leadership in the race to Fifth Generation ("5G") wireless technology deployment. However, the Commission's decision will do little to advance that goal. Instead, without significantly benefitting anyone but Ligado and its investors, the Commission has jeopardized every American's ability to continue to rely on the effectiveness of the U.S. Global Positioning System ("GPS"), a national

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1/ *See* 47 C.F.R. § 1.106.

2/ *See LightSquared Technical Working Group Report*, Order and Authorization, FCC 20-48 (rel. Apr. 22, 2020) ("*Ligado Order*").

utility that has injected $1.4 trillion into the Nation's economy. The risks to the functioning of the nearly 900 million GPS receivers[3/] currently operating in the U.S. far outweigh any marginal contributions that would be realized from the redeployment of 30 megahertz of spectrum originally allocated and licensed for satellite use. Thus, the Commission must set aside the *Ligado Order* and deny the Ligado applications.

I. INTRODUCTION AND SUMMARY

Founded in 1978, Trimble is a leading provider of, among other things, advanced positioning and productivity solutions using Global Navigation Satellite System ("GNSS") technology, including the U.S.-based GPS, as well as laser, optical, and inertial technologies. Trimble has been an active participant throughout this proceeding, both individually and through the GPS Innovation Alliance ("GPSIA") and its predecessor, the U.S. GPS Industry Coalition, and the Coalition to Save Our GPS, to ensure that Ligado's proposed operations (and those of its predecessor-in-interest) do not adversely affect the myriad critical applications that depend on GPS.[4/] The *Ligado Order* fails to do that, which is why Trimble submits this Petition.

As the Commission has explained, "[g]enerally, reconsideration is appropriate where the petitioner shows either a material error or omission in the original order or raises additional facts

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3/ *See* National Space-Based Positioning, Navigation, and Timing Advisory Board, *Twenty-Fourth Meeting*, at 14 (Nov. 2019), https://www.gps.gov/governance/advisory/meetings/2019-11/minutes.pdf.

4/ *See, e.g.*, Comments of Trimble Navigation Limited, IB Docket No. 11-109 (filed Aug. 1, 2011); Comments of Trimble Navigation Limited, IB Docket Nos. 11-109 and 12-340 (filed May 23, 2016) ("Trimble 2016 Comments"); Comments of Trimble Inc., IB Docket Nos. 11-109 and 12-340 (filed July 9, 2018) ("Trimble 2018 Comments"); Letter from James A. Kirkland, Vice President and General Counsel, Trimble Navigation Limited, to Marlene H. Dortch, Secretary, FCC, IB Docket No. 11-109 (filed Oct. 11, 2012) ("Trimble 2012 *Ex Parte* Letter"); Letter from Russell H. Fox, Counsel for Trimble Navigation Ltd., to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed June 19, 2015). Because Trimble has been a party to this proceeding, it has standing to file this Petition under Section 1.106(d)(2) of the Commission's rules. *See* 47 C.F.R. § 1.106(d)(2).

not known or not existing until after the petitioner's last opportunity to present such matters."[5/] The Commission made several material errors and omissions in adopting the *Ligado Order*.

- *First*, it adopted the *Ligado Order* through an opaque process without engaging in a notice-and-comment rulemaking and disregarding key inputs from the federal agencies with expertise in GPS gained from utilizing it as a critical utility in accomplishing their public missions. Instead, the FCC effectively outsourced its decision-making to experts hired by Ligado. In so doing, the Commission violated its obligations under Section 343 of the Communications Act ("Act").

- *Second*, the Commission failed to include a reasoned cost-benefit analysis – merely relying on promises and press releases from Ligado to establish the purported public interest benefits of Ligado's applications, while failing to systematically consider the costs and risks to GPS and the applications and critical activities that depend on it.

- *Third*, it erred by misunderstanding or mischaracterizing agreements between Ligado and a handful of GPS manufacturers to reach the false conclusion that they "concurred" with or supported Ligado's applications.

- *Fourth*, the Commission dramatically underestimated the potential for interference to GPS devices by relying on a vague legal standard of harmful interference and *ad hoc*, limited analyses of Key Performance Indicators ("KPIs") as opposed to the readily measurable and well-established 1 dB metric for measuring interference to GPS devices.

- *Fifth*, even though it acknowledged that an unknown number of the nearly 900 million existing GPS receivers will suffer interference, the FCC's "stringent conditions" intended to mitigate and address incidents of interference are entirely unworkable, especially because the Commission has outsourced the job of policing interference to Ligado itself.

These material errors and omissions require the Commission to set aside the *Ligado Order*, and deny the applications, or at a minimum thoroughly re-evaluate the potential use of Ligado's spectrum for terrestrial operations in a notice-and-comment rulemaking proceeding using the criteria supported by the record and federal agencies, and give more appropriate weight to the facts discussed below.

[5/] *HORIZON CABLE I LIMITED PARTNERSHIP, et al.*, Order on Reconsideration, 10 FCC Rcd 3212, ¶ 7 (1995); *see also Paging Systems, Inc., et al.*, Order on Reconsideration, 23 FCC Rcd 7458, ¶ 8 (2008); *County of Boone, Iowa, et al.*, Order on Reconsideration, 27 FCC Rcd 2359, ¶ 5 (2012).

II. THE COMMISSION USED THE WRONG PROCESSES TO AUTHORIZE LIGADO'S SERVICE

A. Notice-and-Comment Rulemaking Was Required

Ligado's applications contemplate a fundamental repurposing of spectrum. The band in which Ligado proposed to operate has been allocated for MSS communications, the most problematic of which is part of a larger band designated for space-to-earth transmissions. And, as discussed further below, the Commission designated that spectrum for MSS for a good reason – to maintain the "quiet neighborhood" in which satellite uses including GPS could safely coexist. But following grant of Ligado's applications, the Commission will allow Ligado to provide primarily terrestrial services. The Commission should have considered Ligado's modification applications using the same notice-and-comment process it consistently follows in other spectrum reallocation matters, with an ultimate decision made in an open Commission meeting. The Commission had at least nine years to do this, but instead elected to proceed by a waiver and in response to a series of proposals by a private party, Ligado, which stood to profit if the Commission repurposed its spectrum.

The FCC has consistently used notice-and-comment rulemaking to make major spectrum decisions. In repurposing MSS spectrum in the AWS-4 band for terrestrial services and granting the MSS licensee in the band – DISH – the authority to provide those services, the Commission engaged in its regular notice-and-comment rulemaking processes, in which it developed its own proposals and sought comment on the service, technical, assignment, and licensing rules before making its decision.[6/] The Commission also engaged in a rulemaking proceeding when it made

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[6/] *See Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands*, Notice of Proposed Rulemaking and Notice of Inquiry, 27 FCC Rcd 3561 (2012); *Service Rules for Advanced Wireless Services in the 2000-2020/2180-2200 MHz Bands (AWS-4), et al.*, Report and Order, 27 FCC Rcd 16102 (2012). Similarly, in modifying Globalstar's ATC authority to operate a terrestrial low-power broadband network using MSS spectrum in the 2483.5-2495 MHz band, the Commission requested input on the costs and benefits of Globalstar's proposal before adopting an order approving the modification. *See Terrestrial Use of the 2473-2495 MHz Band for Low-Power Mobile Broadband Networks*, Notice of already-licensed millimeter wave spectrum available for mobile use, while allowing incumbent operations to continue.[7/] In fact, nearly every time the Commission considers repurposing spectrum, it engages in an open notice-and-comment rulemaking process.[8/]

Even Ligado itself acknowledged the need for a rulemaking earlier in this proceeding when, in 2012, it submitted a petition for rulemaking asking the FCC to develop operating parameters for terrestrial use of the 1526-1536 MHz band.[9/] By forgoing a full rulemaking proceeding, the Commission shirked its obligation to identify and consider a range of possible options and

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Proposed Rulemaking, 28 FCC Rcd 15351 (2013); *Terrestrial Use of the 2473-2495 MHz Band for Low-Power Mobile Broadband Networks, et al.*, Report and Order, 31 FCC Rcd 13801 (2016) ("*Globalstar Order*").

[7/] *See Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al.*, Notice of Proposed Rulemaking, 30 FCC Rcd 11878 (2015) ("*2015 Spectrum Frontiers NPRM*"); *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al.*, Third Report and Order, Memorandum Opinion and Order, and Third Further Notice of Proposed Rulemaking, 31 FCC Rcd 8014 (2016) ("*2016 Spectrum Frontiers Order*"); *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al.*, Second Report and Order, Second Further Notice of Proposed Rulemaking, Order on Reconsideration, and Memorandum Opinion and Order, 32 FCC Rcd 10988 (2017) ("*2017 Spectrum Frontiers Order*"); *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al.*, Third Report and Order, Memorandum Opinion and Order, and Third Further Notice of Proposed Rulemaking, 33 FCC Rcd 5576 (2018) ("*2018 Spectrum Frontiers Order*").

[8/] *See, e.g.*, *Amendment of the Commission's Rules to Establish New Personal Communications Services*, Notice of Proposed Rulemaking and Tentative Decision, 7 FCC Rcd 5676 (1992); *Amendment of the Commission's Rules to Establish New Personal Communications Services*, Second Report and Order, 8 FCC Rcd 7700, ¶ 88 (1993); *Improving Public Safety Communications in the 800 MHz Band*, Notice of Proposed Rulemaking, 17 FCC Rcd 4873 (2002); *Improving Public Safety Communications in the 800 MHz Band*, Report and Order, Fifth Report and Order, Fourth Memorandum Opinion and Order, and Order, 19 FCC Rcd 14969, ¶ 191 (2004); *Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services Including Third Generation Wireless Systems*, Notice of Proposed Rulemaking, 16 FCC Rcd 596 (2001); *Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands*, Notice of Proposed Rulemaking and Order on Reconsideration, 28 FCC Rcd 11479 (2013); *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Report and Order and Second Further Notice of Proposed Rulemaking, 30 FCC Rcd 3959 (2015) ("*2015 3.5 GHz Order*").

[9/] *See* Petition for Rulemaking, LightSquared Subsidiary LLC, RM-11683 (filed Sept. 28, 2012). While Ligado subsequently withdrew its petition in favor of modifications to its applications, the underlying reason for its petition remains relevant. As Ligado noted, the record "includes a wide diversity of views as to the extent and nature of the overload experienced by many GPS receivers" and "a rulemaking process would create an inclusive and transparent public forum, in which federal agencies, the GPS industry," and others can address all relevant issues and determine a way forward. *See id.* at 4.

conditions as it would ordinarily do in a rulemaking proceeding and, instead, ceded the definition of possible options to a private party.

The Commission also sidestepped an important reform instituted by Chairman Pai, through which drafts of important decisions are released in advance of their adoption at open meetings. The draft of the *Ligado Order* was never released to the public, and it was voted on by the Commissioners over a weekend at the height of a nationwide health crisis that demanded the attention of all affected parties. In adopting this reform, Chairman Pai stated that "releasing these documents – rather than keeping them behind closed doors until after our vote – will increase the public's understanding of our decision-making process, and result in final rules that better serve the public interest."[10/] Among the many public interest benefits of releasing draft decisions is the fact that they afford the public with an opportunity to provide final input to the Commission's decision.

That did not occur in this case. Had the Commission done so, there would have been an opportunity to point out basic flaws in the Commission's decision, such as the inaccurate description of agreements between Ligado and GPS equipment manufacturers, discussed further below. Moreover, critical aspects of the Commission's decision, including the "stringent conditions" to prevent interference, were published for the first time in the decision. As set forth below, these conditions are deeply flawed and impractical in light of real-world conditions. The Commission, on reconsideration, should therefore vacate its decision and deny the applications based on the record or consider Ligado's proposals as part of a full notice-and-comment rulemaking. This rulemaking should consider the long-term implications of reducing the amount of

[10/] News Release, FCC Chairman Pai Takes First Step to Increase Transparency of Rulemakings (Feb. 2, 2017), https://docs.fcc.gov/public/attachments/DOC-343300A1.pdf.

space-to-earth spectrum, especially in light of the now robust innovation occurring in satellite technology.[11/]

B. The Commission Failed to Adequately Consult with Federal Stakeholders

As the steward of federal spectrum use, NTIA was responsible for gathering inputs from affected government agencies on Ligado's proposed network. NTIA did so and received detailed submissions from the Department of Defense ("DoD") and Department of Transportation ("DoT"), among others.[12/] Based on that feedback, NTIA stated that "federal agencies have significant concerns regarding the impact to their missions, national security, and the U.S. economy" and therefore NTIA was "unable to recommend the Commission's approval of Ligado's applications."[13/] The Commission acknowledges those concerns,[14/] but attempts to explain them away by suggesting that the agencies convey no new information or arguments other than pointing to PNT EXCOM

[11/] *See Satellites; The Small and the Many*, THE ECONOMIST (Aug. 25, 2016), https://www.economist.com/technology-quarterly/2016/08/25/the-small-and-the-many (noting potential for rapid innovation in space technology and services over the next decades as a result of emergent small satellite technology); RTI International, *Economic Benefits of the Global Positioning System (GPS)*, at ES-4 (June 2019) ("RTI Study"), https://www.rti.org/sites/default/files/gps_finalreport.pdf ("GPS is not just a service; it is also a platform for innovation. With the support of federal agencies, private enterprise has leveraged GPS to deliver value through precision agriculture, advanced logistics and route optimization, high-speed wireless services, and a host of other applications."); Space Capital and Silicon Valley Bank, *The GPS Playbook*, at 18 (Mar. 2020), https://www.svb.com/contentassets/c0e37e68e9894f5a9719b0dacadb1aaf/the-gps-playbook-svb-2020.pdf (suggesting that the Space-based Communications and Geospatial Intelligence segments have the potential to generate over $1 trillion in equity value over the next decade).

[12/] *See*, *e.g.*, Letter from Mark T. Esper, Secretary of Defense, Department of Defense, to Ajit Pai, Chairman, FCC (Nov. 18, 2019) (urging the Commission to reject Ligado's applications because "[a]ll independent and scientifically valid testing and technical data shows the potential for widespread disruption and degradation of GPS services"); *see also* Letter from Douglas W. Kinkoph, Deputy Assistant Secretary for Communications and Information (Acting), NTIA, to Ajit Pai, Chairman, FCC (Apr. 10, 2020) (attaching letters from the DoD and a memorandum by the Air Force, which stated that nine years of extensive and technically rigorous testing and analysis showed that the proposed Ligado license modification threatens disruption of GPS). Trimble understands that in addition to providing its assessment, NTIA provided the Commission with separate inputs from individual federal agencies. However, in an attempt to conclude that there was no new evidence in the record, the Commission elected not to include that information in the record or address that information in its decision.

[13/] Letter from Douglas W. Kinkoph, Deputy Assistant Secretary for Communications and Information (Acting), NTIA, to the Ajit Pai, Chairman, FCC (Dec. 6, 2019).

[14/] *See Ligado Order* ¶¶ 124-26.

recommendations and the DoT ABC Report, which the Commission finds unpersuasive.[15/] But stating that there was no "new" evidence is not a blanket license for the Commission to ignore the evidence that federal agencies submitted in the past. The fact that all important GPS government stakeholders, after extensive study, strongly recommended denial of Ligado's applications should have been afforded far more than the *pro forma* dismissal they were given in the *Ligado Order*.

The Commission's action also clearly violates Section 343 of the Act, which states that the Commission shall not permit commercial terrestrial operations in Ligado's spectrum until the Commission "resolves concerns" of widespread interference to covered GPS devices, which are defined as GPS devices of the DoD.[16/] The Commission attempts to demonstrate compliance with this requirement by stating that it has resolved *its own* concerns of widespread harmful interference.[17/] But that section does not require the FCC to convince *itself* that there will be no harmful interference. The "concerns" that must be resolved are those of DoD and other federal government entities, which have not been resolved.[18/] The legislation in which Section 343 was enacted further demonstrates that Congress clearly intended to have DoD play a significant role in assessing whether interference concerns from Ligado's operations have been resolved before the Commission can act. The Commission was bound by statute and its past practice to consider the concerns raised by DoD and others,[19/] and its flat rejection of these concerns was a material error.

15/ *See id.* ¶ 126.

16/ 47 U.S.C. § 343.

17/ *See Ligado Order* ¶¶ 129-30.

18/ In addition to the letters submitted on the record, actions taken and statements made by DoD and others after the release of the *Ligado Order* clearly demonstrate they do not view interference concerns as resolved. *See, e.g.*, Theresa Hitchens, *Feds, DoD & Lawmakers Oppose FCC's Ligado 5G Plan*, BREAKING DEFENSE (Apr. 21, 2020) https://breakingdefense.com/2020/04/feds-dod-lawmakers-oppose-fccs-ligado-5g-plan/; Hearing, Senate Armed Services Committee, Department of Defense Spectrum Policy and the Impact of the Federal Communications Commission's Ligado Decision on National Security (May 6, 2020); Joe Gould, *32 Senators to Urge FCC to Reverse Ligado Decision*, BATTLEFIELD TECH (May 15, 2020), https://www.c4isrnet.com/congress/2020/05/14/30-senators-to-urge-fcc-to-reverse-ligado-decision/.

19/ *See* National Defense Authorization Act for Fiscal Year 2017, Pub. L. No. 114-328, Sec. 1698 (2016); *see also* Letter from Adam Smith, Chairman, and William "Mac" Thornberry, Ranking Member,

III. EACH BASIS ON WHICH THE COMMISSION MADE ITS DECISION IS FLAWED

A. The Commission Overstated the Public Interest Benefits of Ligado's Proposed Operations and Failed to Balance the Public Interest Harms

The Commission alleged that Ligado's planned network will advance the goal of bringing advanced communications services, including 5G, to the public, adding that Ligado is "uniquely positioned" to offer industrial IoT ("IIoT") services, particularly in rural areas.[20/] The sole basis for this finding is non-binding statements of intent by Ligado that the Commission should have viewed with considerable skepticism, because Ligado has neither a track record of providing any kind of terrestrial services nor any history of pioneering cutting-edge services,[21/] and its financial stability is

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Committee on Armed Services, U.S. House of Representatives, *et al.*, to Ajit Pai, Chairman, FCC, *et al.*, IB Docket Nos. 11-109 and 12-340 (May 7, 2020) ("We are concerned that your approval of any mitigation efforts not rigorously tested and approved by national security technical experts may be inconsistent with the legislative direction to resolve concerns . . . .").

[20/] *Ligado Order* ¶ 22. An IIoT service primarily for vehicular and utility use does not merit a separate spectrum designation in any case. An IIoT service requires only a small fraction of spectrum for limited uses – indeed, most providers that offer IoT services do it on an ancillary basis, using the guard band of spectrum otherwise used for wireless broadband. *See, e.g.*, *Internet of Things*, T-Mobile, https://iot.t-mobile.com/network/#nbiot (last visited May 16, 2020); Kendra Chamberlain, *Verizon Lights Up Nationwide NB-IoT Network*, FIERCEWIRELESS (May 14, 2019), https://www.fiercewireless.com/iot/verizon-lights-up-nb-iot-network-across-country; Sue Marek, *AT&T Will Launch Nationwide NB-IoT Network in 2019*, SDX CENTRAL (June 20, 2018), https://www.sdxcentral.com/articles/news/att-will-launch-nationwide-nb-iot-network-in-2019/2018/06/. Nor is Ligado "uniquely positioned" to support IIoT services. In addition to the nationwide providers that are already doing so, the Commission has permitted Globalstar to offer a combined terrestrial low-power and satellite network. *See Globalstar Order* ¶ 1. And in allocating spectrum for a range of uses, the Commission has noted that the spectrum can be used for IoT – without creating a separate allocation for the service. *See*, *e.g.*, *2015 Spectrum Frontiers NPRM* ¶¶ 1, 260 (noting that there are expectations for the millimeter wave bands to be used for 5G mobile services as well as IoT applications, among others); *2016 Spectrum Frontiers Order* ¶ 5; *2017 Spectrum Frontiers Order* ¶ 12; *2018 Spectrum Frontiers Order* ¶ 5; *Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, Report and Order and Order of Proposed Modification, FCC 20-22, ¶ 92 (rel. Mar. 3, 2020) ("*C-Band Order*") (allocating spectrum in the 3.7-4.2 GHz band for 5G services and allowing IoT operations in that band).

[21/] *See* Mark Esper, U.S. Secretary of Defense, *The FCC's Decision Puts GPS at Risk*, WALL ST. J. OPINION (May 5, 2020), https://www.wsj.com/articles/the-fccs-decision-puts-gps-at-risk-11588719423 ("There is no evidence that [Ligado] has a technically viable 5G solution."); *Solving Real Problems Doesn't Mean Bailing out Fake Business Plans*, TELECOM, MEDIA AND FINANCE ASSOCIATES, INC. BLOG (Apr. 13, 2020), http://tmfassociates.com/blog/2020/04/13/solving-real-problems-doesnt-mean-bailing-out-fake-business-plans/.

uncertain.[22/] Similarly, the idea that Ligado has the wherewithal to provide rural services, when, as the Commission has recognized elsewhere, even large, well-established carriers have struggled to meet the needs of rural communities without government-provided subsidies, is questionable at best.[23/]

The purported 5G benefits of repurposing Ligado's 30 megahertz of satellite spectrum are equally questionable. A true 5G network requires wide bandwidths in order to deliver the anticipated benefits of faster speeds, lower latency, and increased connections.[24/] The spectrum on which Ligado proposes to offer the service is not internationally harmonized for Ligado's purported 5G uses, significantly diminishing its effectiveness as a 5G band. The Commission also recently made available large swaths of both mid-band and high-band spectrum with block sizes specifically targeted for 5G services, in addition to the substantial amounts of spectrum already, or soon to be, licensed to wireless carriers that can and will be used for 5G.[25/] The FCC is making 350 megahertz

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22/ *See* Andrew Scurria and Drew FitzGerald, *FCC Chairman Backs Ligado 5G Wireless Proposal*, WALL ST. J. (Apr. 16, 2020), https://www.wsj.com/articles/fcc-chairman-backs-ligado-5g-wireless-proposal-11587052018 ("[Ligado] went through a bankruptcy in 2012 . . . after its previous business plans were rejected. . . . [and] had been preparing for the worst as its long campaign to win over the FCC dragged on, engaging financial advisers to explore a possible debt restructuring or second bankruptcy.").

23/ *See, e.g.*, *Establishing a 5G Fund for Rural America, et al.*, Notice of Proposed Rulemaking and Order, FCC 20-52, ¶¶ 1, 2 (rel. Apr. 24, 2020) ("*5G Fund NPRM*") (expressing concern that even with the significant deployment commitments made by major U.S. mobile wireless carriers, "some rural areas will remain where there is insufficient financial incentive for mobile wireless carriers to invest in 5G-capable networks" and therefore proposing to establish a $9 billion 5G Fund to support rural 5G deployments).

24/ *See, e.g.*, *C-Band Order* ¶ 74 ("By allowing new flexible-use licensees to acquire full 100-megahertz blocks, we will ensure that C-band spectrum is licensed in sufficiently wide bandwidths to enable 5G deployments.").

25/ *See, e.g.*, *id.* ¶¶ 3-4 (making 280 megahertz of spectrum in the 3.7-4.2 GHz band available); *2015 3.5 GHz Order* ¶ 1 (opening 150 megahertz in the 3550-3700 MHz band for commercial use); *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, Fifth Report and Order, 34 FCC Rcd 2556 (2019) (making "available millimeter wave (mmW) spectrum, at or above 24 GHz, for fifth-generation (5G) wireless, Internet of Things, and other advanced spectrum-based services"); *see also 5G FAST Plan*, FCC, https://www.fcc.gov/5G (aiming to free up another 2.75 gigahertz of spectrum in the 26 GHz and 42 GHz bands and over 800 megahertz of mid-band spectrum for 5G services).

of mid-band spectrum available for 5G in just the next several months.[26/] Any impact that Ligado's operations will have on the race to 5G will therefore be *de minimis.*

While the Commission's analysis of public interest benefits is limited and flawed, it almost completely ignores the risks and potential costs of its decision, violating the Communications Act, which states that the Commission may only grant licenses if it determines that the "public convenience, interest, or necessity will be served" by such grant.[27/] In considering whether its proposed actions meet those criteria, the Commission has routinely engaged in thorough cost-benefit analyses.[28/] The Commission failed to do that here.

The Commission acknowledged that harmful interference to existing GNSS receivers is possible.[29/] Yet, the *Ligado Order* lacks any meaningful discussion of the role of GPS in the economy or the ubiquity of GPS as an enabling technology in critical infrastructure. With nearly 900 million GPS receivers currently in use, even if interference affected only a small percentage of receivers, the total magnitude of the problem could be substantial. But the Commission made no meaningful effort to estimate the magnitude of interference or evaluate the impact of this interference and, as noted below, relies on ineffective after-the-fact solutions to remedy it. Similarly, while the Commission cites Ligado's self-serving claims about network capabilities and

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26/ *See Auction of Priority Access Licenses for the 3550-3650 MHz Band, et al.*, Public Notice, FCC 20-18 (rel. Mar. 2, 2020); *Auction of Flexible-Use Service Licenses in the 3.7-3.98 GHz Band for Next-Generation Wireless Services, et al*., Public Notice, FCC 20-23 (rel. Mar. 3, 2020).

27/ *See* 47 U.S.C. § 307.

28/ *See*, *e.g.*, *Call Authentication Trust Anchor*, *et al.*, Report and Order and Further Notice of Proposed Rulemaking, FCC 20-42, ¶ 122 (rel. Mar. 31, 2020); *Use of the 5.850-5.925 GHz Band*, Notice of Proposed Rulemaking, 34 FCC Rcd 12603, ¶¶ 63-67 (2019); *Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs*, Notice of Proposed Rulemaking, 33 FCC Rcd 4058, ¶¶ 33-34 (2018); *Unlicensed Use of the 6 GHz Band*, Report and Order and Further Notice of Proposed Rulemaking, FCC 20-51, ¶¶ 229-30 (rel. Apr. 24, 2020). In fact, every single item adopted by the FCC in an open meeting over the last three months has featured a cost-benefit analysis. *See, e.g.*, *5G Fund NPRM; Review of the Commission's Rules Governing the 896-901/935-940 MHz Band*, Report and Order, Order of Proposed Modification, and Orders, FCC 20-67 (rel. May 14, 2020).

29/ *See Ligado Order* ¶¶ 88-91, 97.

job growth, it fails to consider the economic impact of the potential harm to GPS. The economic value of GPS has been estimated to be $1.4 trillion since it was made available for civilian and commercial use.[30/] In fact, GPS is so valuable that a disruption resulting in a loss of GPS service has been estimated to have a $1 billion per-day impact on the U.S. economy.[31/] The *Ligado Order* simply ignores these important facts, and its omission of a cost-benefit analysis renders the FCC's public interest findings meaningless.

Instead, the Commission attempts to convince itself that there is no cost to the economy in creating a loss of GPS capabilities by asserting that interference concerns can be managed. As demonstrated below,[32/] they cannot. But even when it recognizes that there will be costs to addressing interference, it fails to consider specific and quantifiable costs related to that approach. There are tens of thousands of different types of GPS devices used in a variety of activities. Numerous industries – including agriculture, transportation (land, sea, and air), timing, construction, and mining – rely on GPS devices to provide highly accurate and critical positioning services. GPS is also utilized by the military and in a number of public safety applications, not to mention GPS receivers in almost every cell phone. There is no one-size-fits-all solution, and the costs to address the myriad and varying devices would be substantial.

B. The Commission Overstates and Mischaracterizes the Relevance of Ligado's Agreements with GPS Manufacturers.

The Commission relies heavily on what it characterizes as the "coexistence agreements" between Ligado and GPS manufacturers in determining that technical and operational solutions have been developed to address concerns about harmful interference to GPS receivers.[33/] Three of

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30/ *See* RTI Study at ES-1.

31/ *See id.* at ES-4.

32/ *See infra* Section IV.

33/ *See, e.g., Ligado Order* ¶¶ 34, 62, 85.

these agreements were entered into in order to settle lawsuits initiated by Ligado. Only Deere agreed not to object to Ligado's modification applications in return for ending the litigation, but even that agreement explicitly states that it does not support Ligado's applications. Subsequent to the Commission's Order, Garmin reiterated that it "does not support or endorse" Ligado's applications due to the potential effects on certified aviation receivers.[34/] On the eve of the adoption of the *Ligado Order*, the aviation industry, one of the most important groups of manufacturers and users of GPS receivers, made clear its continuing objection to grant of Ligado's applications.[35/] And while Trimble's settlement agreement with Ligado initially indicated support of Ligado's applications with respect to its uplink operations as part of a package of proposals (including study of interference issues by the DoT), it expressly and categorically did *not* agree to the most problematic downlink (or base station) operations in the 1526-1536 MHz band,[36/] nor did it agree with Ligado's proposal to use interference standards other than the 1 dB standard, a linchpin of the FCC's decision.[37/]

[34/] Letter from Scott Burgett, Director, GNSS and Software Technology, Garmin International, Inc., to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340, at 2 (filed May 15, 2020).

[35/] *See, e.g.*, Edward A. Yorkgitis, Jr. Counsel, Aviation Spectrum Resources, Inc., to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340, at 5 (filed Apr. 21, 2020) (explaining that if Ligado's applications are granted without the issues in this letter being adequately resolved, "it would represent a clear and unfortunate step backward in American aeronautical safety communications and in the efficiency of operations in the NAS.").

[36/] *See, e.g.*, Settlement Agreement *attached to* Letter from Gerard J. Waldron, Covington, Counsel to New LightSquared LLC, to Ms. Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed Feb. 3, 2016); Letter from Russell H. Fox, Mintz, Counsel for Trimble Inc., to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed Apr. 20, 2020) ("Trimble Apr. 2020 *Ex Parte* Letter"); Letter from Russell H. Fox, Mintz, Counsel for Trimble Inc., to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed July 26, 2019).

[37/] For high-precision receivers, the most recent PNT EXCOM study ascribed over $31 billion in annual benefits to this class alone. *See* Letter from Bradford W. Parkinson, First Vice-Chair, PNT Advisory Board, to the Hon. Patrick M. Shanahan, Deputy Secretary of Defense, and the Hon. Jeffrey A. Rosen, Deputy Secretary of Transportation, Co-chairs, National Executive Committee for Spaced-base Positioning, Navigation, and Timing, at 2 (Aug. 10, 2018), https://www.gps.gov/governance/advisory/recommendations/2018-08-letter-to-excom.pdf.

Another manufacturer that entered into an agreement with Ligado merely indicated that it had made its receivers more resistant to Ligado's high-powered terrestrial transmissions' interference, but noted that there would be significant costs to such upgrades of future receivers as well as performance tradeoffs. The same manufacturer also estimated that Ligado's proposed operations could affect 500,000 of its existing receivers.[38/]

Rather than assess the actual meaning and true relevance of Ligado's agreements with GPS manufacturers, the Commission drew the unsupported conclusion that the manufacturers "agree[d] that their GPS devices can co-exist with Ligado's proposed terrestrial operations."[39/] In fact, the contents of the agreements with GPS manufacturers other than Deere, Garmin, and Trimble have not been made public, nor has the Commission inquired about their content. For example, if Ligado had agreed to pay the expenses of this handful of manufacturers to upgrade or replace their affected receivers, the willingness of these manufacturers to enter into agreements would not, as the Commission suggests, be evidence that Ligado's operations will not interfere with many of the nearly 900 million receivers currently in use or the equipment and applications of the many other manufacturers that do not have agreements with Ligado. The Commission was therefore unjustified in relying on Ligado's agreements with a handful of GPS manufacturers[40/] to support its decision.

[38/] *See* Letter from Michael Ritter, President, Hexagon Position Intelligence, to Ms. Marlene H. Dortch, Secretary, FCC, RM-11681, *et al.* (filed May 7, 2018) ("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."); Theresa Hitches, *Exclusive GPS Fight Erupts as Trimble Accuses Ligado of "Inaccurate" Claims in FCC Ruling*, BREAKING DEFENSE (May 8, 2020), https://breakingdefense.com/2020/05/exclusive-gps-fight-erupts-as-trimble-accuses-ligado-of-inaccurate-claims-in-fcc-ruling/ (quoting Hexagon, NovAtel's Swedish parent firm, as stating "the coming spectrum change may significantly affect more than a half million units of older generation NovAtel receivers that were not designed to handle this new spectrum challenge").

[39/] *Ligado Order* ¶ 26.

[40/] Moreover, the Commission is simply wrong that the manufacturers who have agreements with Ligado account for the majority of GPS receivers. *See id.* ¶ 34. The *Ligado Order* contains virtually no discussion of the size and contours of the market for GPS receivers. But even a cursory review of comprehensive industry data compiled by the European Commission would have corrected this misapprehension. *See* European Global Navigation Satellite Systems Agency, *GSA GNSS Market Report*, at 12, 37, 73, 81, 89, 97 (2019), https://www.gsa.europa.eu/system/files/reports/market_report_issue_6_v2.pdf

C. The Record Does Not Support the Commission's Approach for Determining the Potential for Harmful Interference to GPS Devices.

As the record demonstrates, the Commission made material errors in its harmful interference analysis. Trimble and others have repeatedly explained that navigation systems operate and experience interference differently from communications systems.[41/] Unlike communications systems, which are very high powered relative to satellite signals and operate *above* the noise floor, wide bandwidth, spread spectrum GPS signals are *below* the thermal noise floor when they are received.[42/] While GPS receivers are typically designed to withstand adjacent-band transmissions hundreds of millions of times stronger than GPS signals, they can be "overloaded" by "undesired" (potentially interfering) mobile broadband transmissions in adjacent frequencies. As a result, both the Commission and the International Telecommunication Union ("ITU") have historically maintained a quiet radio frequency spectrum neighborhood for GNSS services like GPS.[43/] In fact, Ligado's MSS spectrum and GPS share a band of nearly 100 megahertz designated principally for space-to-earth transmissions. GPS "grew up" over the past four decades in this quiet environment and has become a ubiquitous and critical public utility. The Commission should have placed a very high bar on disturbing this quiet radiofrequency environment with ubiquitous terrestrial use, but it did the exact opposite. The *Ligado Order* treats the interference issues as it would in terrestrial-to-

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(explaining that diversity in the downstream GNSS industry is increasing, and, as of 2017 encompassed over a thousand companies globally for the first time). The receivers sold by the parties with whom Ligado has agreements is likely a few tens of millions of the 900 million devices in use, if that.

41/ *See, e.g.*, Comments of the GPS Innovation Alliance, Docket No. 181130999-8999-01, RIN 0660-XC044, at 7 (filed Jan. 22, 2019) ("GPSIA 2019 NTIA Comments"); Comments of the GPS Innovation Alliance, ET Docket No. 17-340, at 5 (filed Jan. 31, 2018) ("GPSIA 2018 TAC Comments"); *Improving Federal Spectrum Systems*, 114th Cong. 1, at 4 (Oct. 16, 2015) (written testimony of GPSIA) ("GPSIA 2015 Testimony"), https://docs.wixstatic.com/ugd/a5ea08_187ad436a8ce470991a8389a9fa189c3.pdf ("GPSIA 2015 Testimony").

42/ GPS signals come from satellites that orbit more than 12,000 miles above the earth, transmitting with no more power than a 50-watt light bulb, and signals that are received by GPS devices are at a power level that is less than a millionth of a billionth of a watt.

43/ *See, e.g.*, GPSIA 2018 TAC Comments at 11; GPSIA 2019 NTIA Comments at 8; Trimble 2012 *Ex Parte* Letter at 5-6.

terrestrial service cases. The Commission's failure to account for the basic differences between communications and navigation devices means the entire premise of its decision is erroneous.

The Commission bases its conclusions regarding interference on the Roberson and Associates ("RAA") and National Advanced Spectrum and Communications Test Network ("NASCTN") reports instead of the DoT ABC Report.[44/] Unlike the DoT ABC Report, which was prepared by experts with deep knowledge of GPS, both the RAA and NASCTN reports, as the Commission acknowledges, were funded by Ligado itself and conducted by communications engineers with no meaningful GPS experience or background – producing a "results first" product.[45/] Although the Commission may certainly rely on reports prepared by a participant in a proceeding, it is inappropriate for the Commission to do so here when it has neutral third-party analyses from U.S. government experts on which to base its determinations. Indeed, this is the very approach the Commission took in earlier phases of this proceeding. For example, in 2011, the Commission relied on balanced third-party feedback by establishing the technical working group, which brought together NTIA, Ligado (then LightSquared), the GPS community, and appropriate federal agencies to "fully study the potential for overload interference to GPS devices and to identify any measures necessary to prevent harmful interference to GPS."[46/] The Commission inexplicably abandoned that practice in attempting to resolve interference issues in its decision.

The Commission's exclusive reliance on the RAA and NASCTN reports is even more inexcusable because of the very limited results they provide. As the Commission acknowledges, RAA tested only 27 GPS devices falling within the cellular, general location/navigation, and high-precision categories, and the NASCTN report upon which the Commission heavily relied tested

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44/ *See Ligado Order* ¶¶ 37-38, 61.

45/ *See id.* ¶¶ 37-38.

46/ *LightSquared Subsidiary LLC Request for Modification of its Authority for an Ancillary Terrestrial Component*, Order and Authorization, 26 FCC Rcd 566, ¶ 41 (2011).

only *fourteen* devices.[47/] With tens of thousands of different kinds of GPS receivers in operation today, basing conclusions on such a small sample size is irresponsible. Unlike the RAA report, prepared by a communications engineer, and which was paid for by Ligado, *the NASCTN report expressly acknowledges that there is no way of knowing whether the devices it tested are representative of GPS receivers as a whole.*[48/] The Commission glosses over this critical discussion and extrapolates the results of tests of 14 receivers to the nearly 900 million GPS receivers currently in use.

The NASCTN tests had other severe methodological limitations, which were extensively documented by industry, including the fact that it only analyzed the effects of interfering signals on *stationary* GNSS devices. Yet, the Commission dismissed fourteen pages of methodological critiques submitted by industry in a footnote.[49/] The Commission's reliance on such limited studies is a monumental gamble with the future of GPS, with extremely poor odds.[50/]

[47/] *See Ligado Order* ¶¶ 37-38.

[48/] *See* William F. Young, *et al.*, *NIST Technical Note 1952, LTE Impacts on GPS, Final Report,* (Feb. 2017), https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1952.pdf (recognizing concerns that "there are tens of millions of GPS devices in circulation" and stating that because "[t]he distribution and quantity of units, models, or manufacturers necessary to achieve a [devices under test] population that is 'representative' of this complete market has not been established . . . [t]he relationship between the comprehensive market and our test population (or that of previous tests) is . . . not clear").

[49/] *See* Letter from F. Michael Swiek, Executive Director, GPS Innovation Alliance, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340, at 2 (filed July 13, 2017) ("GPSIA July 2017 *Ex Parte* Letter") (attached to this Petition as Exhibit B). Section 1.106(f) of the rules specifically permits the filing of supplements. *See* 47 C.F.R. § 1.106(f) (stating that "[t]he petition for reconsideration and any supplement thereto shall be filed within 30 days from the date of public notice of the final Commission action" and applying the 25-page limit only to the petition for reconsideration).

[50/] While the Commission recognizes that the receivers tested were limited, it claims that there was no opposition from GPS manufacturers about whether the devices were representative of the market. *See Ligado Order* ¶ 86. That is patently false. The GPS industry repeatedly explained the inadequacy of the limited pool of devices tested. *See, e.g.*, GPSIA July 2017 *Ex Parte* Letter at 2; Letter from J. David Grossman, Executive Director, GPS Innovation Alliance, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340, at 5 (filed Dec. 20, 2019) ("GPSIA Dec. 2019 *Ex Parte* Letter").

Even more concerning, these limited studies and sample sizes actually showed the potential for interference, as the Commission acknowledges.[51/] For example, of the devices RAA tested, one out of 12 general location/navigation receivers was impacted when applying the impaired GPS constellation configuration in a dynamic GPS scenario, and an impact was observed for seven out of 11 high-precision receivers.[52/] In other words, of the small sample size studied in the tests relied upon by the Commission, nearly 30 percent of the 27 receivers suffered some form of interference, even with their flawed methodologies.

Perhaps the Commission's most significant error is its rejection of the use of the 1 dB increase in the Carrier-to-Noise Power Density Ratio ("C/N_0") metric utilized in the DoT ABC Report, and prior studies, to assess potential interference. The GPS industry explained that the 1 dB standard has a long and well-established history in both international and domestic regulatory proceedings of protecting GNSS operations from harmful interference.[53/] The Commission, however, asserts that it will not use a 1 dB C/N_0 degradation metric because it does not assess whether the actual performance of a GPS device is affected and, therefore, does not directly address whether there would be any "harmful interference" as defined by the Commission.[54/] This is simply wrong. The record conclusively demonstrated that a 1 dB adverse change was correlated with degradation of GPS receiver performance.[55/]

51/ *See Ligado Order* ¶¶ 80-81.

52/ *See id.* ¶¶ 79-80.

53/ *See* GPSIA Dec. 2019 *Ex Parte* Letter at 9-10; GPSIA 2018 TAC Comments at 5-6 (noting, for example, that the ITU has consistently applied an interference to noise ratio of -6 dB (equivalent to a 1 dB rise in the noise floor) in proceedings related to GNSS, other non-communications services, and some radiolocation services); *see also* GPSIA 2019 NTIA Comments at 10; Trimble 2018 Comments at 2-3.

54/ *See Ligado Order* ¶¶ 48-49.

55/ Christopher Hegarty, *et al.*, Loss of Lock Analysis, GPS-ABC Workshop VI, at 6 U.S. Dep't of Trans. (Mar. 30, 2017), https://ntlrepository.blob.core.windows.net/lib/61000/61200/61227/5-Loss_of_Lock_-_30Mar17.pdf (last visited May 20, 2020); U.S. Dep't of Trans., GPS Adjacent Band Compatibility Assessment, Space-Based PNT Advisory Board, at slide 16 (Dec. 7, 2016), https://www.gps.gov/governance/advisory/meetings/2016-12/vandyke.pdf (last visited May 22, 2020). *See also* Guy Buesnel, *et al.*, Moreover, as the GPS industry has highlighted, the 1 dB standard measures whether a new service causes a 1 dB degradation in a receiver's C/N_0 or a 25 percent increase in the noise floor; in other words, a persistent increase of 25 percent in the interfering noise that affects GPS receivers.[56/] The Commission never acknowledges the 25 percent increase figure, but instead merely mentions in passing a "small rise" in background noise.[57/] Given the difficulty of extracting very faint GPS signals from existing noise, a 25 percent increase in noise is not small, but quite substantial. Industry also explained how protecting against greater increase in noise was necessary to accommodate the technical characteristics of navigation receivers and ensure the accuracy, integrity, continuity, and availability of the GNSS signal.[58/] The Commission simply ignored or rejected this evidence without reasoned explanation or contrary evidence in the record.

Worse, the FCC accepted arguments from Ligado's communications engineers that "[r]adio noise occurs throughout the spectrum and a small rise in background noise, however undesirable, does not by itself constitute harm to a service,"[59/] and that there are variations in this metric even without any signal from Ligado.[60/] This argument is specious and highlights the Commission's lack of appreciation of navigation technologies like GNSS – it is the equivalent of arguing that since air pollution levels vary from day-to-day due to atmospheric conditions, weather, and other factors, the addition of a persistent polluting source that increases polluting emissions by 25 percent is not harmful.

Investigations into Observed Anomalous GNSS Receiver Behavior when Subjected to Adjacent Band Noise, SPIRENT (Sept. 2018), https://www.gps.gov/governance/advisory/meetings/2018-12/buesnel.pdf.

56/ *See, e.g.*, GPSIA 2019 NTIA Comments at 3, 10; Letter from J. David Grossman, Executive Director, GPS Innovation Alliance, to Ms. Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed Feb. 18, 2020).

57/ *See Ligado Order* ¶ 49.

58/ *See, e.g.*, GPSIA Dec. 2019 *Ex Parte* Letter at 2; Trimble 2018 Comments at 4-7; GPSIA July 2017 *Ex Parte* Letter at 4-5.

59/ *Ligado Order* ¶ 49.

60/ *See id.* ¶¶ 50, 52.

By rejecting the 1 dB standard, the Commission was able to simply define away the findings of the multi-year DoT study of adjacent-band interference, as well as prior studies that found that substantial numbers of GPS devices would suffer harmful interference from Ligado's proposed operations.[61/] This is not surprising, since at its proposed reduced power levels, the Ligado signal will be 10,000,000 times stronger than the GPS signal as received on earth. Ligado is permitted to place base stations operating at this power level every 433 meters, a very dense network topography. A reduction in power does not resolve interference issues because a higher density of base stations operating at lower power levels in an area could create the same level of interference.[62/] The DoT results measuring interference within 100 meters of a base station show that substantial numbers of GPS devices will suffer interference in a substantial portion of the coverage area of Ligado's base station network.[63/] Instead of the preexisting standard supported by the international GNSS community and sound GPS engineering considerations, the RAA and NASCTN studies used KPIs of their own formulation to assess whether proposed power and OOBE levels would pose harm to GPS devices. As the GPS industry has demonstrated, and as further explained in Exhibit B, KPIs do not provide a reliable basis for assessing harmful interference.[64/]

Because the Commission relies solely on Ligado's consultants – who are not experts in GNSS devices – to support its contention that harmful interference can be resolved, instead of the record, which shows just the opposite, the Commission's determination must be overturned.

[61/] *See* DOT Testing Results attached as Exhibit A.

[62/] *See, e.g.*, Trimble Apr. 2020 *Ex Parte* Letter at 2; Letter from M. Anne Swanson, Wilkinson Barker Knauer, LLP, Counsel to Garmin, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340, at 3 (filed Sept. 10, 2019).

[63/] *See* Exhibit A at 1-2.

[64/] *See, e.g.*, GPSIA July 2017 *Ex Parte* Letter at 2; GPSIA Dec. 2019 *Ex Parte* Letter at 5; Trimble 2018 Comments at 3; Trimble 2016 Comments at 17; GPSIA 2015 Testimony at 5.

IV. THE COMMISSION'S MITIGATION PLANS FOR RESOLVING INTERFERENCE ARE UNREASONABLE AND WILL BE INEFFECTIVE

In acknowledging the potential for harmful interference, the Commission proposes certain mitigation measures and imposes several conditions on Ligado. Ligado is required to establish and maintain a toll-free telephone number for the public to report apparent incidences of interference from Ligado's operations to GPS operations.[65/] Upon notice of a GPS disruption, Ligado is required to notify the Commission and *may* be required to cease transmissions. These non-interference conditions are based on typical models used by the Commission to resolve disputes between sophisticated FCC licensees (*e.g.*, broadcasters, wireless carriers, etc.) and are completely impractical for resolving interference issues between individual device owners such as consumers, farmers, or private pilots.

First, the Commission does not consider how a GPS device owner can reliably determine whether its device has suffered interference and then attempt to demonstrate this to Ligado to obtain relief. The FCC's traditional models were developed in contexts where the effects of interference are observable by affected users or at least identifiable by professional engineers with suitable, readily available off-the-shelf equipment.[66/] The circumstances in which individual GPS device owners will experience harmful interference will be very different.

The *Ligado Order* appears to endorse a harmful interference standard employing vaguely defined KPIs for each individual type of GPS receiver or associated application. As an initial matter, the Commission does not discuss such important practicalities as how the appropriate KPIs will be determined for each of the thousands of different applications and use cases in which GPS

65/ *See Ligado Order* ¶ 146.

66/ *See, e.g.*, *Promoting Expanded Opportunities for Radio Experimentation and Market Trials under Part 5 of the Commission's Rules and Streamlining Other Related Rules, et al.*, Report and Order, 28 FCC Rcd 758 (2013) (applying "stop buzzer" requirements to experimental operations, which involve the sophisticated coordination of operations, to allow *licensees*, which themselves are experienced, to contact the experimental operator to resolve interference concerns).

receivers are used. Nor does it discuss how it can be determined whether the degradation of performance under those KPIs in a particular case is "harmful" interference or "just" interference.[67/] The Commission has neither the experience, expertise, nor resources with respect to GPS to provide meaningful guidance on these issues. With nearly 900 million receivers in use, the process the Commission envisions is simply unworkable.

Even in the unlikely event that these critical threshold issues are resolved, the further question of how an individual device owner can detect and then demonstrate harmful interference under those criteria is even more problematic. In the NASCTN study, determining whether receiver performance had been degraded required an elaborate test setup in a government spectrum lab (part of the reason, in fact, why NASCTN only tested 14 receivers). The Commission fails to address how an individual farmer or consumer can reach a similar determination with a mobile GPS device operating in the field. In fact, no individual device owner will be equipped to do so.

Harmful interference, defined as degradation of performance, is a relative measure – whether in the presence of an interfering signal a receiver is performing worse than it would have in the absence of that signal. Individual device owners cannot be expected to establish a "baseline" for such a comparison. Similarly, there will be no way to prove degradation of the accuracy of the position readout of a device, since there will be no way to determine the actual position of a device which an individual device owner is operating in the field, and show how it deviates from the position provided by the degraded receiver. In short, the Commission committed the fundamental error of confusing a method for determining the potential for harmful interference in the aggregate with an effective means of policing interference in the real world. This error further demonstrates the Commission's lack of appreciation of GPS technology.

[67/] *See Ligado Order* ¶ 49.

Second, it is simply wrong to put the burden on individual businesses and consumers to report interference. Unlike, for example, wireless carriers or broadcasters, consumers and businesses that use GPS are not capable of assessing the radiofrequency environment, let alone determining the source of the degraded performance of their devices. Many will simply assume the device is malfunctioning, and replace it at their own expense, or complain to their local equipment dealer, retailer, or the maker of the device (which often is not the manufacturer of the embedded GPS receiver) causing needless expense, which the Commission does not attempt to estimate. Assuming a device owner can determine that harmful interference has occurred, and find the toll-free number Ligado is required to establish, the Commission leaves it up to Ligado to report the "anticipated measures to be taken to resolve the disruption."[68/] The Commission does not discuss the remedy if Ligado wrongfully denies that interference has occurred.[69/]

Third, the Commission's discussion of additional means to mitigate interference is equally flawed. The *Ligado Order* imposes obligations on Ligado to repair or replace federal government agency equipment if it causes interference, but provides no rationale for taking a different approach for non-federal government devices. To support its decision, the Commission suggests that the GPS manufacturers that have agreements with Ligado "may have already repaired or replaced potentially affected GPS receivers (whether military or civil devices),"[70/] based on a filing by Ligado in which Ligado merely notes that it has *offered* to repair and replace devices "*as necessary*."[71/] This is

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68/ *Id.* ¶ 146.

69/ The Commission's thinly-stretched enforcement staff is ill-equipped to address the information it receives. Complaints from even a small portion of the nearly 900 million GPS devices in the marketplace will quickly overwhelm the FCC's resources. And even if the Commission is capable of responding to reports of interference, by the time it acts, the damage will be done. Consumers and businesses will be left with unreliable information or no GPS service at all – a potentially catastrophic outcome when GPS is relied upon for critical life-saving services.

70/ *Ligado Order* ¶ 102.

71/ *See* Letter from Gerard J. Waldron, Covington, Counsel to Ligado, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed Apr. 12, 2020).

hardly a basis for a decision that could impose substantial costs on millions of owners of GPS devices.

The *Ligado Order* also suggests that GPS receivers can be retrofitted or upgraded with different antennas or enhanced filtering.[72/] This is simply not the case. As the GPS industry has explained, if filtering was required, there would be significant financial and performance costs.[73/] GPS receivers are usually not stand-alone devices and do not generally have detachable antennas that can be easily "swapped out." Rather, a GPS receiver is generally embedded in a device that uses the positional output of the receiver for another purpose. Such devices cannot simply be opened up and modified, and even if they could, the costs of doing this with millions of receivers would be substantial. The Commission fails to estimate these costs and weigh them in its public interest analysis of Ligado's proposal.

In short, the Commission's basic approach to resolving harmful interference – which it acknowledges will occur – is based upon inapplicable models and has many paths to complete failure. These interference protection conditions are not "stringent" in any way. Rather, they rely almost exclusively on the fox, Ligado, to guard the henhouse. On reconsideration, the Commission must conduct a far more comprehensive analysis of the likely magnitude of potential incidents of interference, along with a detailed consideration of the effectiveness of possible real-world solutions, taking into consideration the hundreds of millions of GPS receivers in use.

72/ *See Ligado Order* ¶ 89.

73/ *See, e.g.*, Letter from James A. Kirkland, President, Trimble, to the Hon. Fred Upton, Chairman, Energy and Commerce Committee, U.S. House of Representatives, and the Hon. Greg Walden, Chairman, Communications and Technology Subcommittee, Energy and Commerce Committee, U.S. House of Representatives, at 5-6 (dated Apr. 25, 2014) (Question 9), *attached to*, Letter from Catherine Wang, Bingham, Counsel to Deere & Company, to Ms. Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed Sept. 18, 2014); GPSIA 2015 Testimony at 5-6.

V. CONCLUSION

For the reasons set forth above, and pursuant to Section 1.106 of the Commission's rules, Trimble respectfully requests that the Commission reconsider its decision granting Ligado's applications for modification.

Respectfully submitted,

/s/ James A. Kirkland

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May 22, 2020

CERTIFICATE OF SERVICE

I, Elana R. Safner, hereby certify that on May 22, 2020 a copy of the foregoing Petition for Reconsideration of Trimble Inc. was served by electronic mail[1/] on the following:

Gerard J. Waldron
Covington & Burling LLP
One CityCenter
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<u>*/s/ Elana R. Safner*</u>
Elana R. Safner

[1/] Pursuant to Section 1.47(d) of the FCC's rules, the party to be served may agree to accept service in an alternative form. *See* 47 C.F.R. § 1.47(d). Counsel for Ligado has agreed to service by electronic mail of this Petition.

Exhibit A

Summary Analysis of Department of Transportation Adjacent Compatibility Study

DOT TESTING RESULTS

May 22, 2020

The DoT Adjacent Band Compatibility study conducted rigorous tests of 80 GPS receivers [DOT page 23] falling into 6 categories, including General Aviation (NonCertified) (GAV), General Location/Navigation (GLN), High Precision/Networks (HPR), Timing (TIM), and Cellular (CEL). [DOT page 23]. The study used testing results to determine interference impact under "… use cases representative [of] each receiver category." [DOT page 78]. In the Ligado Order, the FCC criticized one output of the study, which was an interference tolerance mask (ITM) which, based on the study results would protect all of the receivers tested. The FCC stated that "[w]e …strongly disagree that interference protections should be based on the worst performing receivers, and this is the basis for the interference protection levels in the DOT ABC Report." [FCC paragraph 57]. The FCC order, however, ignored data compiled by DOT that showed EIRP levels that would cause interference to 10%, 50%, and 90% of the tested receivers, in addition to the permissible EIRP levels that would protect all (100%) of the tested receivers. Using this data, the percentage of tested receivers that would suffer harmful interference under the 1 dB C/N_0 protection criteria at the FCC authorized transmission power of 9.8 dBW EIRP, assuming a minimum inter-station separation distance of 433 meters in a hexagonal grid could be determined. The following is a summary of DOT results extrapolated for a transmission power of 9.8 dBW.

Table A (for Micro Urban transmitter category)

Receiver Category	**Percentage of receivers interfered with at > 1 dB C/N0 At a range of 10m**
General Aviation	Between 50% to 90%
General Location & Navigation	Between 50% to 90%
High Precision	Between 50% to 90%
Timing	Between 10% to 50%, very close to 50%

Receiver Category	**Percentage of receivers interfered > 1 dB C/N0 At a range of 100m**
General Aviation	Between 10% to 50%
General Location & Navigation	Between 10% to 50%
High Precision	Between 10% to 50%, very close to 50%
Timing	Between 10% to 50%, closer to 10%

In the case of cellular receivers, none of the devices would be interfered with at 9.8 dBW at 10m or 100m. Cellular receivers, however, are narrow-band receivers that do not use the full GPS signal, and so have better interference rejection characteristics at the cost of poorer performance in producing a location.

Interference at a range of 100m for a base station network with minimum inter-station separation distance of 433 meters in a hexagonal grid is equivalent to having interference over 20% of the total operational space. Since GPS receivers are mobile, it can be expected that a significant number of GPS receivers will regularly enter and exit the area in proximity to base station towers where the receivers will suffer harmful interference. In other words, interference will repeatedly interrupt a significant percentage of GPS receivers on an ongoing basis as the receivers move around in Ligado's base station footprint.

A summary of the data collected by the DOT is displayed in the Table below. Each red circle indicates the range within which the EIRP authorized for Ligado base stations (i.e. 9.8 dBW) would fall, as indicated above.

Table B

Receiver Category	Stand off distance (m)	Percentage of Receivers Experiencing >= 1 dB Interference Versus EIRP				
		None (all protected)	10%	50%	90%	All (none protected)
Cellular	10	11.7 W	37.2 W	37.2 W	37.2 W	37.2 W
	100	1.2 kW	>1.5 kW	>1.5 kW	>1.5 kW	>1.5 kW
General Aviation	10	1.2 mW	1.9 mW	758.6 mW	95.5 W	95.5 W
	100	123.0 mW	195.0 mW	77.6 W	>1.5 kW	>1.5 kW
Gen Loc & Nav	10	1.0 mW	2.1 mW	416.9 mW	66.1 W	104.7 W
	100	104.7 mW	208.9 mW	41.7 W	>1.5 kW	>1.5 kW
High Precision	10	75.9 uW	758.6 uW	302.0 mW	75.9 W	151.4 W
	100	7.8 mW	77.6 mW	30.9 W	>1.5 kW	>1.5 kW
Timing	10	9.8 mW	30.9 mW	12.3 W	97.7 W	123.0 W
	100	977.2 mW	3.1 W	1.2 kW	>1.5 kW	>1.5 kW

For example, ***at least*** *50% of the General Aviation receivers will experience interference at a 10 meter standoff distance from a Ligado tower, while* ***at least*** *10% of General Aviation receivers will experience interference at a 100 meter standoff distance from a Ligado tower.* The precise percentage of receivers which will suffer interference cannot be determined due to the lack of granularity in the reported data, but the actual total percentage of receivers suffering harmful interference based on the actual distribution of results is expected to be within the indicated ranges.

DOT Data Presentation

The DoT report provides, in Appendix B, "Statistical and Bounding Interference Tolerance Masks (ITMs) for 1 MHz and 10 MHz LTE Interference Signals". The lower bound curve (at the 1530 MHz point, experimentally determined) in each of the Statistical and Bounding ITMs, is propagated back through the model of antenna patterns and path loss to determine the Maximum Tolerable Power Levels that protect all receivers – the values provided in Table ES-1 below. If the same propagation assumptions are applied to the other four curves (90%, 50%, 10%, and upper bound) in the Statistical and Bounding ITMs, then one can determine the percentages of receivers that will suffer harmful interference by various ranges of LTE transmission EIRP. The resulting power levels associated with each percentage bound are compiled in Table B above. The relevant tables and plots included in the DOT Report from which the results in Table B are derived follow.

Table ES-1: Maximum Tolerable Power Level for GPS/GNSS Receivers at 1530 MHz

Deployment	Stand off distance (m)	Max Tolerable EIRP (dBW)			
		GLN	HPR	TIM	CEL
Macro Urban	10	-31.0	-41.9	-20.6	10.9
	100	-11.0	-21.9	-0.6	31
Micro Urban	10	-29.8	-41.2	-20.1	10.7
	100	-9.8	-21.1	-0.1	30.8

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
Micro Urban	10	1 mW	76 μW	9.8 mW	11.7 W
	100	104 mW	7.8 mW	1 W	1.2 kW

DOT Report, Exec Summary page V (page 5 of pdf file)
Difference between Macro and Micro Antennas (derived from above chart)

Receiver Category	Stand off distance (m)	Difference in Max Tolerable EIRP (dB)			
		GLN	HPR	TIM	CEL
Micro Urban vs. Macro Urban	10	1.2	0.7	0.5	-0.2
	100	1.2	0.8	0.5	-0.2

- ITM Power levels read-off from DoT Report, Appendix B: Statistical and Bounding ITMs, for determination of Statistics versus EIRP Causing >= 1 dB Interference

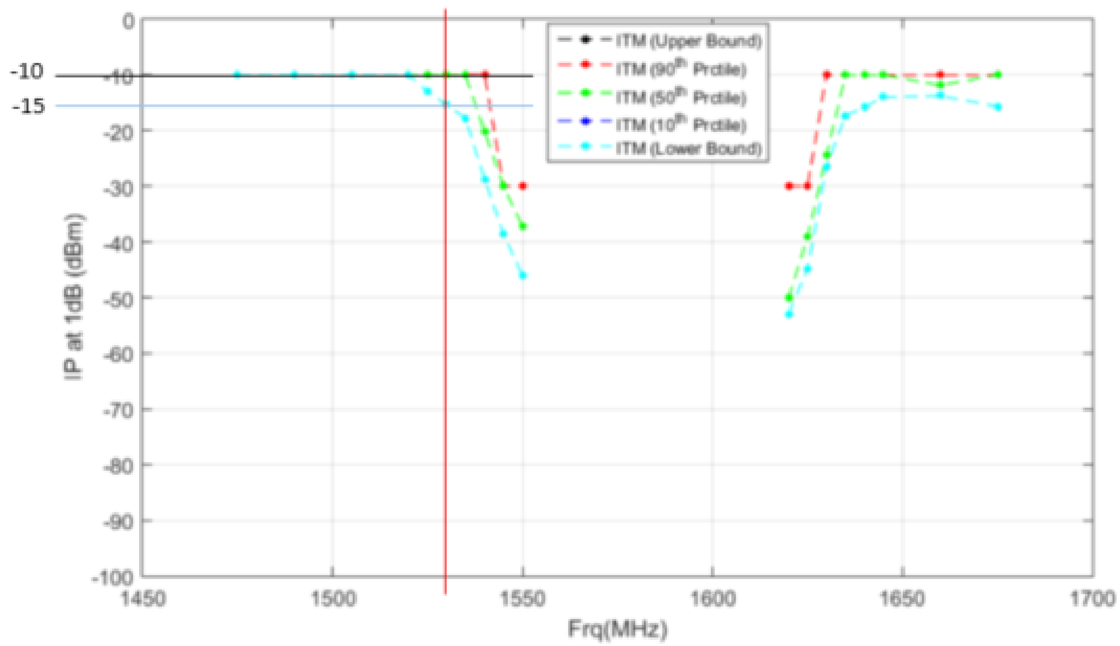

Figure B-21: 10 MHz GPS L1 C/A Statistical Mask Results for Cellular receivers
[DOT Appendix B, page 130]

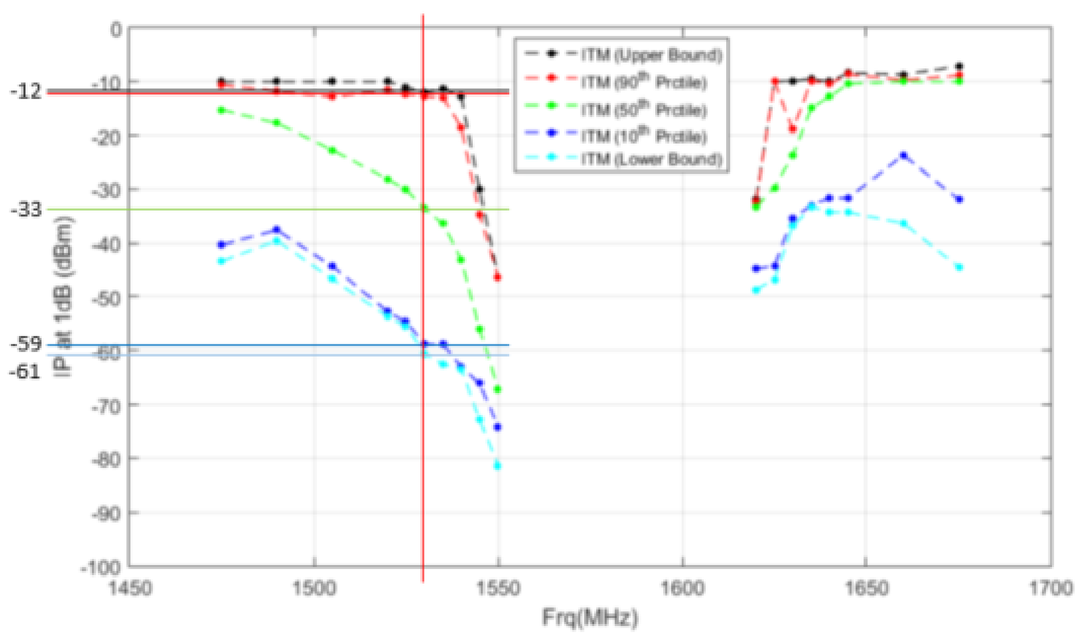

Figure B-23: 10 MHz GPS L1 C/A Statistical Mask Results for General Aviation receivers
[DOT Appendix B, DOT page 131]

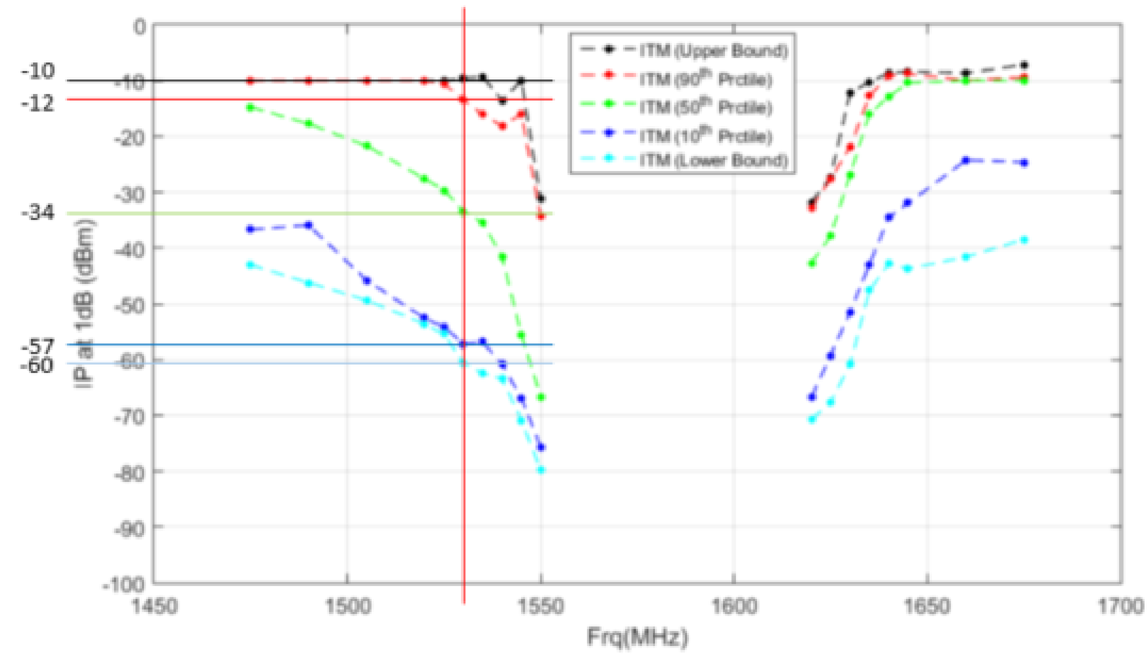

Figure B-25: 10 MHz GPS L1 C/A Statistical Mask Results for General Location Navigation receivers [DOT Appendix B, page 132]

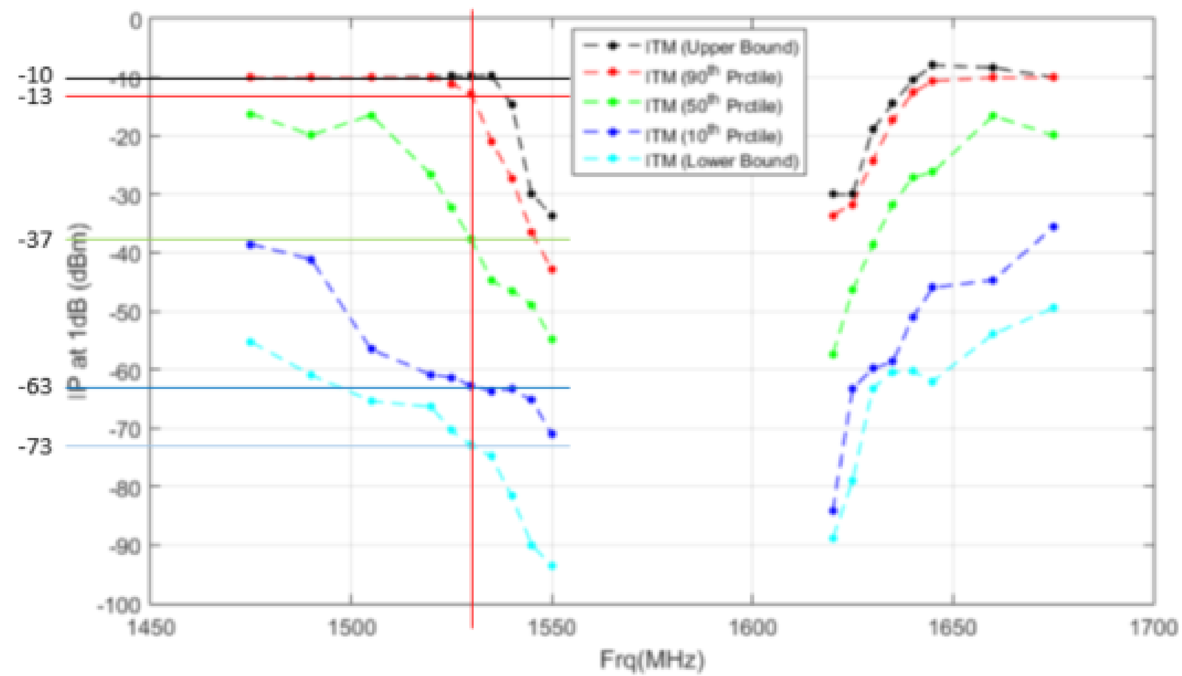

Figure B-27: 10 MHz GPS L1 C/A Statistical Mask Results for High Precision receivers [DOT Appendix B, page 134]

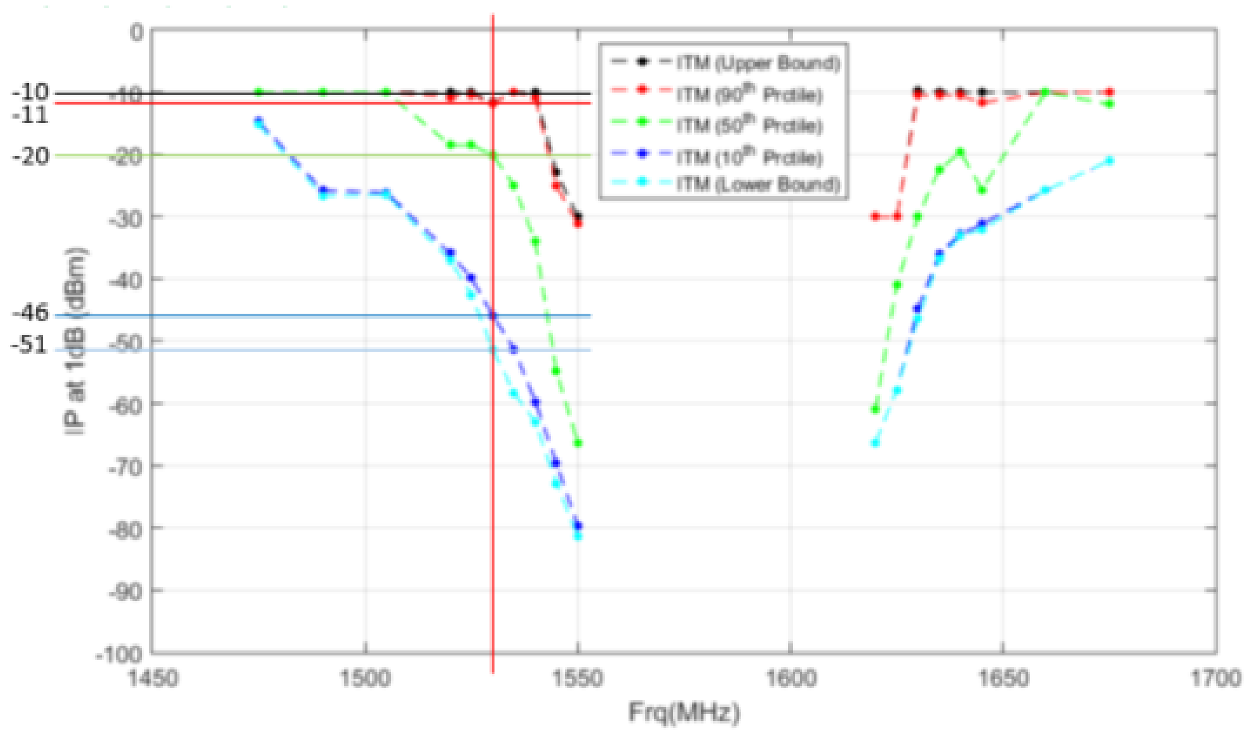

Figure B-32: 10 MHz All GNSS Aggregated Minimum Statistical Mask Results for Timing receivers
[DOT Appendix B, page 137]

DECLARATION OF KURT ZIMMERMAN

1. My name is Kurt Zimmerman. I provide this declaration in support of Exhibit A attached to the Petition for Reconsideration submitted by Trimble Inc. ("Trimble") of the Commission's *Order and Authorization* that granted applications submitted by Ligado Networks LLC ("Ligado") to modify its Mobile Satellite Service authorizations so that it may deploy a nationwide terrestrial wireless network in the 1526-1536 MHz, 1627.5-1637.5 MHz, and 1646.5-1656.5 MHz bands.

2. I am Engineering Director of Trimble.

3. I have over 25 years' experience with GPS technology including 9.5 years with Trimble in a range of technical and commercial roles with detailed knowledge of Trimble GPS technologies, products, customer applications and markets.

4. I hold a PhD degree in Electrical Engineering from Stanford University.

5. I have reviewed those elements of Exhibit A, which contain analyses of the U.S. Department of Transportation's GPS Adjacent Band Compatibility Assessment of the potential interference from Ligado's proposed operations to GPS receivers receiving signals in adjacent spectrum, and find those analyses to be accurate and complete.

6. I declare under penalty of perjury that the foregoing is true and correct.

Kurt R. Zimmerman

Kurt Zimmerman 5/22/2020

Executed on: May 22, 2020

Exhibit B

GPSIA July 2017 Ex Parte – NASCTN

July 13, 2017

Via ECFS and IBFS

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Written *Ex Parte* Presentation

LightSquared Request to Modify Its ATC Authorization, **IB Docket No. 12-340**; **IBFS File Nos. SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SAT-MOD 20101118-00239; SES-MOD-20121001-00872**; LightSquared Technical Working Group, **IB Docket No. 11-109**; **DA 16-442**

Dear Ms. Dortch:

The GPS Innovation Alliance ("GPSIA") respectfully submits this *ex parte* filing on the appropriate standard for evaluating harmful interference to Global Navigation Satellite System ("GNSS") devices in order to provide context for the Commission's consideration of recent test results published by the National Advanced Spectrum and Communications Test Network ("NASCTN").[1]

The NASCTN tests contribute to the available technical information on the measurement of interference to GNSS devices.[2] The test results provide both direct and indirect support for the use of the historic and well-established standard for determining harmful interference – whether an interfering signal produces a 1 dB decrease in the Carrier-to-Noise Power Density

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1 WILLIAM F. YOUNG, ET AL., LTE IMPACTS ON GPS, NIST (2017), http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1952.pdf ("NASCTN Report").

2/ NASCTN's goal was to:

> "establish a test method to investigate the impact of adjacent band long-term evolution (LTE) transmissions on global positioning system (GPS) L1 receivers in tracking and reacquisition modes. . . . [T]he resulting test method and data . . . could be used to: 1. establish the integrity of this and other test methods and ensure the quality of the collected data, including detailed uncertainty analysis of both the test conditions and the device under test (DUT) response, 2. enable a connection to previous testing efforts focused on adjacent band activity impacts on GPS device performance, and/or 3. support additional, in-depth testing by other interested parties on measurand behavior as reported by the [Devices Under Test]. The methods, testing, results, and analyses neither assumed nor identified pass/fail thresholds." NASCTN Report at 1.

Ratio ("C/N_0") of the affected receiver.[3] The standard is also amply supported not only by precedent and use in applicable technical standards but is also based upon well understood technical characteristics of GNSS receivers and the impact of noise on the performance of these receivers, all of which remain valid today.

I. The 1 dB Standard Remains the Appropriate Standard for Evaluating Harmful Interference to GNSS Receivers

The NASCTN results provide direct support in the form of test data which establish a direct correlation between decreases in C/N_0 of the tested receivers and degradation in measured key performance indicators ("KPIs"). The report provides indirect support by highlighting the extreme complexity of measuring the effect of interfering signals on the selected KPIs of GNSS devices and the limitations of the data obtained from such tests. For example, while the vast majority of GNSS receivers are designed and intended for mobile operation (as might be expected for devices that are intended to provide location information while moving in vertical and horizontal space), the NASCTN test method only analyzed the effects of interfering signals on stationary GNSS devices. Moreover, for all of the effort put into the testing, data were collected on only four KPIs (and even these were not available for all devices). No tests were conducted to determine the effect of any detected degradation in these indicators on the actual performance of the critical applications for which the tested GNSS receivers are used, such as precise machine control or aviation navigation. Nor is it at all clear how such tests could ever be performed in a rigorous and reproducible manner since such applications operate in dynamic real-world environments, not a laboratory.

II. GPSIA Reiterates Its Members' Previously Stated Positions with Respect to the Technical Parameters Which Have Been Agreed Upon with Ligado

As noted in the applications for modification submitted by Ligado Networks LLC ("Ligado") for its Mobile Satellite Service ("MSS") licenses,[4] each of GPSIA members Deere, Garmin and Trimble have negotiated agreed-upon technical parameters for terrestrial use of some or all of Ligado's licensed MSS spectrum. GPSIA refers the Commission to the applications and associated filings for the details.[5] In general, the agreements set forth (1) technical requirements

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3 For ease of reference, this standard is referred to as the "1 dB standard."

4 *See* Applications of LightSquared Subsidiary LLC, Narrative, IBFS File Nos. SAT-MOD-20151231-00090, SAT-MOD-20151231-00091, and SES-MOD-20151231-00981 ("Modification Applications"). In this *ex parte*, we use the term "Ligado," "New LightSquared," and its subsidiary "LightSquared Subsidiary LLC" interchangeably.

5 *See, e.g.*, New LightSquared, *Ex Parte* Presentation, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835 (Dec. 8, 2015) ("LightSquared December 8 *Ex Parte*"); New LightSquared, *Ex Parte* Presentation, IB Docket No. 12- 340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835 (Dec. 17, 2015) ("LightSquared December 17 *Ex Parte*"); New LightSquared, *Ex Parte* Presentation, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SES-MOD- 20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091 (Feb. 3, 2016).

pertaining to terrestrial operations on frequencies from 1627.5 MHz upwards; and (2) limitation on use of the 1545-1555 MHz band solely for satellite downlink purposes, and agreement that Ligado will not seek any terrestrial authorization for the 1537-1555 MHz band.[6] On behalf of these members, GPSIA refers the Commission to the agreements and acknowledges the continued adherence of Deere, Garmin and Trimble to the positions set forth in the agreements.

Beyond the specific technical resolutions in the agreements, there are policy issues of general applicability that have been the subject of extensive controversy in the above-referenced dockets for which the parties to the settlement agreements have "agreed to disagree." One such issue is the appropriate standard for determining harmful interference to GNSS devices. The agreed upon technical requirements do not constitute agreement with, or endorsement of, any party's position on the correct metrics or standard for determining the potential for harmful interference to GNSS devices and applications. Whatever action the Commission takes with regard to the specific Ligado Modification Applications in light of the parties' agreements, it continues generally to have a responsibility to ensure that newly proposed or modified terrestrial operations do not cause harmful interference to GPS and other GNSS systems, and GPSIA and its members continue to believe that the 1 dB standard is the appropriate standard.

III. <u>The NASCTN Test Data Support the 1 dB Standard</u>

GPSIA and its members believe that as a matter of general policy, the FCC should continue to evaluate claims of harmful interference using the metric that the GNSS industry, the FCC, and the National Telecommunications and Information Administration ("NTIA") have used in various contexts for many years – whether there is a 1 dB decrease in the C/N_0 of the affected receiver. Based upon well understood GNSS engineering considerations, a 1 dB change is associated with quantifiable changes in the overall noise to which GNSS receivers are subject, with equally well understood effects on receiver operation. Use of this standard is necessary to ensure the accuracy, integrity, continuity, and availability of the GNSS signal.

The NASCTN data, with respect to the relatively small sample of receivers tested, show direct correlation between a 1 dB drop in C/N_0 and degradation of the KPIs analyzed. The NASCTN testing program, however, highlights the difficulty of both measuring interference effects on KPIs and the variability of test results. Moreover, failing to gauge GNSS performance based on a universal, quantifiable metric that accounts for all uses and variations in signal would undermine technological innovation by subjecting the design and development of future equipment to tremendous uncertainties about the amount of "noise" present in the radiofrequency environment. Use of the 1 dB standard has allowed GPS to thrive and all GNSS systems to serve a critical role in ensuring safety-of-life services and propelling economic growth.[7]

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6 The agreements entered into by Deere and Garmin also include provisions regarding the technical requirements for use of the 1526-1536 MHz band. *See* LightSquared December 8 *Ex Parte* at 2-3; LightSquared December 17 *Ex Parte* at 19-23. The agreement entered into by Trimble does not. Comments of Trimble Navigation Limited at 2, IB Docket No. 12-340, *et. al* (filed May 23, 2016).

7 "The carrier-to-noise power ratio, C/N_0, is an important factor in many GPS receiver performance measures. It is computed as the ratio of recovered power, C, (in W) from the desired signal to the noise density N_0 (in W/Hz)." Betz, Hegarty, and Ward, *Satellite Signal Acquisition, Tracking, and Data*

A. The 1 dB Standard Is Supported by Well Understood and Critical Aspects of GNSS Engineering

For GPS and GNSS systems to meet the needs of existing and future users, it is essential that they be able to deliver a signal that is accurate, has integrity, and is available and continuous in nature. The same four attributes – accuracy, integrity, availability, and continuity – are affected by interference in varying ways, and degradation of any one of these four performance parameters will diminish the usefulness of GNSS to significant numbers of users.[8]

Accuracy is the difference between a GPS device's indicated position, velocity, and time ("PVT") and its actual PVT at any given moment. The accuracy requirements are highly use-case dependent, varying from tens of meters to less than a centimeter. In earthquake monitoring, for example, accuracy is extremely important both for measuring the imminence of quakes and for calculating post-quake displacement.[9] Survey GNSS, precision agriculture, and intelligent transportation systems could not continue to function without accuracy. Yet, accuracy alone is insufficient for most GNSS applications; they also need integrity, availability, and continuity.

Integrity is the ability of GNSS systems to provide *timely* warning to users of problems in the system or equipment and to shut itself down when it is unable to meet accuracy requirements. Safety-of-life aviation operations, such as precision approach and landing as well as Terrain Awareness Warning Systems ("TAWS"), depend on integrity of the signal and system to avoid disasters and prevent loss of life. Without integrity, airport safety records would be worse and controlled flight into terrain accidents would rise.[10] Like accuracy, integrity alone is insufficient to ensure functioning of GNSS.

Demodulation, in UNDERSTANDING GPS PRINCIPLES AND PRACTICE, 185 (C. Hegarty and E. Kaplan, eds., Artech House 2006).

8 "Non-interference with radionavigation RF spectrum is crucial. All domestic and international radionavigation services are dependent on the uninterrupted broadcast, reception and processing of radio frequencies in protected radio bands. Use of these frequency bands is restricted because stringent accuracy, availability, integrity, and continuity parameters must be maintained to meet service provider and end user performance requirements." DEP'T OF DEFENSE, DEP'T OF HOMELAND SECURITY, AND DEP'T OF TRANSPORTATION, 2008 FEDERAL RADIONAVIGATION PLAN, at 1-14, http://www.navcen.uscg-.gov/pdf/2008_Federal_Radionavigation_Plan.pdf.

9 For background on U.S. utilization on GPS in earthquake monitoring and warning, *see generally* D.D. Green, et al., *Technical Implementation Plan for the ShakeAlert Production System in An Earthquake Early Warning System for the West Coast of the United States*, U.S. Department of the Interior, U.S. Geological Survey (2014).

10 "It is important to note that the mandatory installation of TAWS into U.S. commercial aircraft is considered by many to have made the single greatest impact to improving U.S. commercial aviation safety in the last 20 years." Letter of Michael P. Huerta, Acting FAA Administrator, to The Honorable Lawrence E. Strickling, Administrator, NTIA, Jan. 27, 2012, https://ntl.bts.gov/lib/44000/44300-/44302/06_NTIA_Letter_Enclosure_4_-_2012_Jan_25_-_StatusReportAssessOfPlanned_LSQ_ATC_-TransIn1526to1536MHz_-_FAA.pdf.

Availability describes how often a GNSS system is available for use when it satisfies accuracy and integrity requirements. A GNSS-based service that only provides PVT information with high integrity for short and unpredictable bursts is unsuitable for most applications. For example, even a momentary degradation of service during an aircraft precision approach or flight close to terrain may trigger a missed approach procedure requiring a pilot to climb to a safe altitude and then wait to be readmitted to the landing sequence. Simply put, all, if not most, ongoing uses require changes or suspension of operations if GNSS becomes momentarily unavailable. Data show that GPS, as it currently functions, meets service availability requirements nearly 100% of the time.[11]

The fourth attribute, *continuity*, evidences GPS's ability to provide the required level of service without unscheduled interruption. Momentary episodes of interference can significantly disrupt continuity for many use cases or applications. Providing high levels of continuity in the face of unpredictable and random interference is particularly difficult and may make potential applications of GNSS unviable. For example, the time between unscheduled interruptions must be long to ensure that standard surveying operations can be conducted, driverless cars can navigate down the highway, and ambulances can reach unfamiliar destinations.[12]

Critical engineering considerations associated with GNSS receivers highlight the potential for degradation in performance in the presence of interfering noise. GNSS, as a navigation system, operates differently than radio communications systems. The primary measurement in GNSS is the timing of bit transitions in the navigation signal. Precise timing and positioning requires sub-nanosecond measurement of bit edges. Accurate measurement of bit edges, in turn, requires wide receiver bandwidth. Also, effective multipath rejection requires wideband signals to discriminate between those signals directly from the satellites versus those undesired reflected signals. Unlike communications systems, which operate above the noise floor, spread spectrum GPS signals are below the thermal noise floor when they are received.[13] The cumulative effects of interference can easily increase the noise floor and degrade performance. Even a small increase in the noise floor may affect any one of the four parameters of accuracy, integrity, availability, or continuity in unexpected or dramatic ways. Each of the attributes can be degraded by varying amounts.

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[11] *See* WM. J. HUGHES TECHNICAL CENTER, GLOBAL POSITIONING SYSTEM (GPS), STANDARD POSITIONING SERVICE (SPS), PERFORMANCE ANALYSIS REPORT, REPORT #92 (2016), http://www.nstb-.tc.faa.gov/reports/PAN92_0116.pdf.

[12] These four performance attributes are internationally recognized and defined. For instance, in 2001, the International Civil Aviation Organization adopted "Standards and Recommended Practices" or "SARPs" that, since 2001, have both defined and set requirements for provision of accuracy, integrity, availability, and continuity of GNSS signals by member countries. *See, e.g.*, Amendment 76 to the International Standards and Recommended Practices and Procedures for Air Navigation Services, at Table 3.7.2.4-1. Furthermore, other international bodies have also recognized the requirements for accuracy, integrity, continuity, and availability. *See* ITU Recommendation ITU-R M.1477, Annex 5 at Section 4; see also European GNSS Agency, "Report on the Performance and Level of Integrity for Safety and Liability Critical Multi-Applications," May 2015, at 11, http://www.gsa.europa.eu/sites/-default/files/calls_for_proposals/Annex%202.pdf.

[13] *See* UNDERSTANDING GPS PRINCIPLES AND PRACTICE, *supra* note 6, at 247.

GNSS system operators and the GNSS industry have found that monitoring changes in a receiver's C/N_0 provides a quantifiable and empirical measure of receiver performance that directly influences all of the four attributes. C/N_0 is directly related to signal to noise ratio ("SNR") and bit error rate ("BER") and is the actual measure of noise and stress in tracking loops.[14] So like BER and SNR, C/N_0 is a direct measurement of receiver performance, rather than a downstream measurement of use-case dependent parameters (such as position error) and is therefore the most appropriate parameter for consideration in an interference analysis. Use of C/N_0 as an interference metric also allows system designers and spectrum regulators to carefully allocate interference to various sources as the net effect of interference is the sum of the individual interference sources, each of which has been expressed in dB. Use of C/N_0, in other words, permits both aggregation of interference and the apportionment of interference among multiple sources.[15]

A 1 dB decrease in C/N_0 is associated with quantifiable changes in the noise to which GNSS receivers are subject, as well as quantifiable effects on performance related variables. A decrease of 1 dB in C/N_0 produces roughly a 25 percent increase in noise due to interference. In many contexts, degradation of 1 dB or more is sufficient to convert acceptable service to marginal service.[16] For example, a 1 dB reduction in C/N_0 from the minimally acceptable operating point will push the Wide Area Augmentation System ("WAAS") word error rate ("WER") above the maximum allowable level of 10^{-3} for certified aviation devices.[17] And while the NASCTN test simulated two WAAS satellites, it did not measure the impact of interference on WER. WAAS represents a carefully engineered component of the GPS system in which the effects of many attenuation and interference sources have been taken into account to reach an operating point that meets strict requirements. Reducing C/N_0 by 1 dB causes the system to no longer meet those requirements.

A 1 dB reduction in C/N_0 is also associated with a tenfold decrease in mean time between cycle slips. Most GNSS systems rely on continuous tracking of the signal carrier of each satellite being tracked to attain maximum accuracy. By continuously tracking the carrier and measuring its phase at the time of measurement (the carrier phase), relative motion with respect to the satellites can be measured to sub-centimeter levels. A cycle slip interrupts this continuous carrier phase, forcing the tracking loop to reacquire the carrier, and then re-initiating the carrier

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14 As experts note, "[a]n accurate measure of C/N_0 in each receiver tracking channel is probably the most important mode and quality control parameter in the receiver baseband area." *Id*. at 233.

15 M. RICHHARIA, SATELLITE COMMUNICATIONS SYSTEMS DESIGN PRINCIPLES, 102 (McGraw-Hill 1995) ("The total noise at the receiver is the summation of noise from all sources . . . . ").

16 Memorandum from National Space-Based PNT Executive Steering Group to Administrator, NTIA, June 14, 2011, at 4, https://www.ntia.doc.gov/files/ntia/publications/ligtsquared_assessment_-report_07062011.pdf.

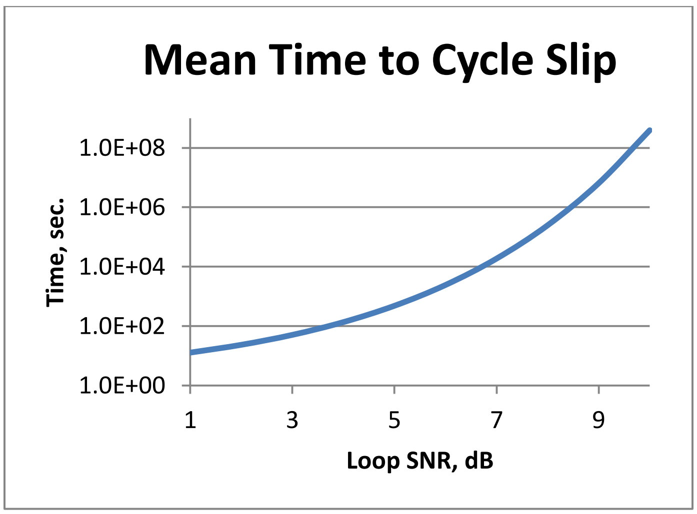
17 RTCA DO-327, Section D.1.5.

phase measurement. Lack of continuous carrier phase renders many high precision applications unavailable.[18]

In addition, all GNSS applications track the pseudo random noise code ("PRN code") from selected satellites in view – this is accomplished in the code tracking loop. The code tracking loop synchronizes a locally generated replica PRN code with the PRN code broadcast from the satellite. This synchronization allows the receiver to make a precise measurement of the starting edge of the first bit of the PRN sequence as it repeats. With this code phase information, the receiver can determine how long it took the satellite signal to reach the receiver and consequently the distance to the satellite. As the noise floor rises, the increased noise makes it more difficult to precisely synchronize the replica PRN code to the broadcast signal, resulting in increased error in the measured distance to the satellite. In dynamic applications with wider tracking loop bandwidths, small increases in the noise floor yield substantial changes in Coarse Acquisition code tracking error, especially in reduced signal scenarios in which the receiver is operating close to its acquisition sensitivity threshold.

Degradation as a result of increased noise may occur before the point at which there has been a 1 dB reduction in C/N_0, or, that is, before the point at which the noise due to interference has increased by 25 percent. This is particularly true in challenging use cases in which signal levels may be attenuated by foliage or structures (for example, suburban streets or "urban canyons," respectively), or in which signal reception is changing due to dynamic effects, such as large trucks passing on the highway or aircraft "pitch and roll" during normal maneuvering at takeoff, landing, or en-route. It is critical that the margin established in the design of the GPS system for effects such as these not be eroded by allowing interference levels (only measured in

18 As shown in the chart in this footnote, the average time between cycle slips, or disruptions in carrier phase, which cause measurement reinitialization, decrease by an order of magnitude with a 1 dB reduction in loop SNR (which tracks directly with C/N_0). In other words, cycle slips occur 10 times more frequently when C/N_0 is reduced by 1 dB. This chart is based on the equation $\tau=\pi^2\alpha I_0(\alpha)/2B_L$, where α is the signal to noise ratio, B_L is the loop bandwidth and τ is the mean time to cycle slip. W. LINDSEY AND C. CHIE, PHASE LOCKED LOOPS, at p. 24 Formula 47 (IEEE Press 1986).



ideal conditions) to cause degradation to the GPS system in excess of the 1 dB standard. This point is substantiated by NASCTN test results showing more rapid degradation of performance metrics with increasing noise in "distressed" environments.

Given these characteristics and fundamental benefits, C/N_0, as an indicator of interference, not surprisingly has a long history of use not only in navigation, but also in radar and communications. For example, radars operating in the radiodetermination service bands are similarly affected by interference and quantify it in terms of the interference to noise ratio.[19]

B. The NASCTN Tests Provide Limited Additional Data

According to recent estimates, there are approximately 750 million GNSS receivers in use in North America.[20] While estimates of the number of unique types of devices in use are not available, it would not be unreasonable to estimate that, at least tens of thousands of different GPS receiver and antenna combinations types are in use. NASCTN tested fourteen unique devices and twenty configurations of GNSS receivers.[21] As the NASCTN report acknowledges, "[t]he distribution and quantity of units, models, or manufacturers necessary to achieve a DUT population that is 'representative' of this complete market has not been established. The relationship between the comprehensive market and our test population (or that of previous tests) is therefore not clear."[22] The NASCTN Report also did not attempt to compare its test results to prior tests, or analyze any differences, as the Report notes:

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19 "If power spectral density of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power spectral density becomes simply I_0+N_0. An increase of about 1 dB would constitute significant degradation, equivalent to a detection-range reduction of about 6%. Such an increase corresponds to an (I + N)/N ratio of 1.26, or an I/N ratio of about –6 dB." *See Recommendation ITU-R M.1463-3, Characteristics of and Protection Criteria for Radars Operating in the Radiodetermination Service in the Frequency Band 1215-1400 MHz*, INTERNATIONAL TELECOMMUNICATION UNION, at p. 8 Section 3 (2015).

20 5 EUROPEAN GNSS AGENCY, MARKET REPORT 33 (2017), https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf.

21 The NASCTN LTE tests included five GLN receivers, three of which provided useable C/N_0 data while under test, and six High Precision (HPP) receivers, of which four were unique models (*i.e.*, two were the same model). For HPP standalone receivers, there are test results for 5 configurations, DUT 7 to DUT 10. NASCTN also tested RTK devices as a subset of HPP devices with additional features. There were four RTK receivers, representing two manufacturers. Two of the four RTK receivers served as rovers, and the remaining two served as base stations. For RTK receivers, there are test results for four combinations of two receiver models and two antenna models, DUT 11-Ant A, DUT 11-Ant B, DUT 12-Ant C, and DUT 12-Ant D. For comparison, the Department of Transportation tested 18 GLN and 35 HPP receivers in its Adjacent Band Compatibility study. *See Test Plan to Develop Interference Tolerance Masks for GNSS Receivers in the L1 Radiofrequency Band (1559-1610 MHz),* DEPARTMENT OF TRANSPORTATION (2016), https://ntl.bts.gov/lib/55000/55400/55473/Draft_DOT_GPS_Adjacent_Band_Compatibility_Assessment_Test_Plan.pdf.

22 NASCTN Report at 1.

> "Comparison among results of different test campaigns . . . requires an understanding of any differences in test conditions, devices, and parameters. Specific examples include GPS and LTE signal parameters, power levels, and test environments. Understanding these factors is crucial to drawing conclusions based on the aggregate of these heterogeneous test results. These types of analyses are beyond the scope of this project, but may be undertaken by other interested parties such as the GPS and cellular communications industry, government agencies, or spectrum regulators."[23]

In terms of the test methodology itself, the NASCTN tests analyzed effects on GNSS receivers in only a single fixed position in the lab. Thus, no measurements of velocity, acceleration, or jerk performance and their effects on KPIs were taken.[24] Since the vast majority of GNSS receivers are intended to be used in mobile applications, this is a substantial limitation, and the effects of including dynamic tests as well are unknown.

C. The NACSTN Data Support the Use of the 1 dB Standard

For the reasons discussed above, 1dB degradation would be expected to adversely affect multiple user metrics, including acquisition time and position accuracy. Though not directly measured by NASCTN, availability, integrity, and continuity are all affected by degradation of acquisition time and accuracy.[25] In fact, the NASCTN test data show a clear correlation between C/N_0 degradation and the other metrics evaluated and therefore support the use of the 1 dB standard to determine harmful interference. The test results also show increased effects of changes in C/N_0 in "stressed" test conditions which are more likely to represent real world conditions in many cases.

Time To First Fix ("TTFF") performance is vital to users of high-precision receivers. Until it attains signal tracking and position fix (*e.g.*, TTFF), a receiver does not produce a useful position measurement, so position accuracy alone is not an indicator of user performance capability. TTFF affects the total availability of use of the high precision position information. The need for increased time to re-acquire satellites and to fix cycle ambiguities on a high precision receiver can significantly degrade performance to the users. Many high-precision applications on heavy machinery require availability near 100% for users to gain full utility and productivity from their equipment.

With respect to High Precision receivers, comparison of the C/N_0 plots with the TTFF measurements for HPP and RTK receivers in the NASCTN results shows that TTFF performance degradation is concurrent with an interference-induced 1 dB drop in C/N_0.[26] Based on these estimates, the level of LTE interference that affects TTFF occurs on average within

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23 *Id.*

24 Velocity is the first derivative of position with respect to time, acceleration the second derivative, and jerk the third derivative. Thus, measuring position in a static simulation without considering these derivative effects limits the utility of the NASCTN data.

25 Accuracy was not assessed in any significant or meaningful way since no dynamic testing was performed. In addition, NASCTN only measured position accuracy.

26 *See* Appendix, Table1.

approximately 3 dB of the 1 dB C/N_0 degradation point, showing a clear connection between signal reception, as measured by C/N_0, and the user experience with respect to TTFF.

The NASCTN test results also show a close correlation between degradation in C/N_0 and the positional accuracy of GLN receivers tested. The test results highlight a significant limitation on the test methodology using devices in a stationary position, which distorts results for devices with certain filter characteristics. DUT 3, Figure 6.21 (page 142) is a good example of when the position error begins to increase at the same time the C/N_0 begins to degrade in the presence of the interfering signal. Upon close examination, the position error begins to increase at about -20 dBm of LTE power incident upon the DUT. This correlates well to figure 6.20 (page 141), where DUT 3 shows a C/N_0 degradation at the same power level. DUT 3, Figure 6.21 also clearly shows how the position error grows significantly as the C/N_0 degrades in the presence of noise, actually reaching nearly 40 meters at the limit compared to a baseline of approximately 0.5m.

DUT 1, Figure 6.21 (page 142) at a cursory reading seems to indicate position error is reduced in the presence of severe interference. Under the laws of physics, however, the error in a measurement increases as the signal to noise ratio of the signal decreases. This is where knowledge of the implementation of the GPS receiver's positioning filtering becomes critical. In the case of DUT 1, as the level of interference increases and the C/N_0 decreases, the positioning filter begins to significantly de-weight the measurements with lower C/N_0 and "pin" its reported position to the last known position when the measurement noise was lower.[27] This technique only produces reasonable results when a GPS receiver is stationary and is a critical reason why any sort of use-case or KPI testing must include a dynamic scenario, not just a stationary one.

Further, with about -15 dBm of LTE power incident upon DUT 1, its "pinned" position jumps to a new position which is of greater error. Later in the test, the "pinned" position jumps back to a lower error position. This behavior is also apparent in DUT 2, Figure 6.21 (page 142). More examples of position pinning are apparent in the GLN results in Section 6.5 ("LTE Power Level Sweeps for Limited GPS Power Exposure").

The NASCTN testing also demonstrates greater negative impacts of potential interference in scenarios when GPS signal power and number of satellites are limited.[28] The NASCTN test program's "limited" GPS scenario represents more real-world conditions than the nominal GPS scenario with full-power on all satellites.[29] GPS receivers are expected to operate well in

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[27] As the interference increases, the positioning filter will actually start to reject measurements, which paradoxically may lower the overall positioning error if the "pinned" position is a good estimate of the actual position.

[28] *See* NASCTN Report Section 6.5, at 233-59.

[29] *See* NASCTN Test Report at Section 2.2.2, at 20-22 for a detailed description of the GPS constellations simulated in the NASCTN test. The "limited" scenario for positioning receivers was an adjustment to the "normal" nominal scenario constellation and has reduced power and fewer satellites. This exposure stressed the ability of GPS receivers to acquire lock through reduced C/N_0 levels. The adjusted constellation was limited to eight L1 C/A and two WAAS signals. The satellite exposure levels at the DUT were distributed across four target values – a pair of satellites at each of -128.5 dBm, -133.5 dBm, -138.5 dBm, and -143.5 dBm EIIP at the DUT (in test implementation, satellite exposure values

obstructed signal conditions as might be encountered in a downtown "urban canyon" or under dense tree cover. In these situations, the number of satellites in view, as well as their C/N_0, can be significantly reduced. In this test scenario, the satellite power levels varied from nominal to 15 dB below nominal in 5 dB steps. This test scenario clearly illustrates the point that every dB of C/N_0 is valuable – it could be the difference between having a fix or not having one.

For example, in Figure 6.111 (page 236), DUT 1 exhibits the "position pinning" behavior clearly as the position filter in this device struggles to process weak signals, several of which are at reduced C/N_0. Conversely, DUT 3 in Figure 6.111 also exhibits the position pinning behavior, but in this case, it pins its position to the correct position solution for the entire test. As stated previously, a dynamic test in this limited GPS signal environment would have been illustrative of the effect of reduced C/N_0 on the position accuracy of the devices. In Figure 6.116, when UL1 is tested, the results exhibit both position pinning behavior in DUT 1, and the more straightforward increase in position error as the C/N_0 decreases in DUT 2 and DUT 3.

The NASCTN "limited" GPS scenario results for HPP and RTK receivers are shown in Table 2, labeled as the "stress" results for each DUT. These results show that the 1 dB C/N_0 result is fairly consistent compared to the nominal constellation results (per DUT). For example, DUTs 7, 8, 9-Ant C, 9-Ant D in Figure 6.26 (page 147) all had nearly the same 1 dB C/N_0 value for nominal and unstressed constellations. This validates the use of 1 dB C/N_0 as the most appropriate metric of receiver performance when exposed to interference, as it is consistent across the widest range of GPS constellation conditions.

After close inspection and review, the NASCTN data actually illustrate a major difference between the nominal and stressed constellation scenarios: the occurrence of "no lock," which happens at a much lower interference level, for all receivers when the GPS constellation is stressed. For example, in Figure 6.121 (page 246), DUT 8 has a "no lock" value 11.6 dB lower for the stressed constellation than the nominal, and DUT 10 has a "no lock" value 15.3 dB lower for the stressed constellation than the nominal. Any other metric (such as position error) would vary with constellation stress in similar manner to the "no lock" condition. Consequently, such a test would yield different results for every GPS operating condition. Any metric that does not produce consistent results despite normal variations in the constellation is not appropriate for gauging receiver performance.

IV. <u>Conclusion</u>

The NASCTN test results confirm what GPSIA has said all along: the historic standard for determining harmful interference – whether an interfering signal produces a 1 dB decrease in the C/N_0 of the affected receiver – continues to be the most appropriate metric for assessing the impact on GPS. The standard is well supported by precedent and is also based upon well understood technical characteristics of GNSS receivers and the impact of noise on the performance of these receivers.

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were -128.5 dBm 2.7 dB, -133.5 dBm 2.7 dB, -138.5 dBm 2.7 dB, and -143.5 dBm 2.7 dB EIIP at the DUT).

Pursuant to Section 1.1206(b)(2) of the Commission's rules, an electronic copy of this letter is being filed for inclusion in the above-referenced dockets. Please direct any questions regarding this filing to the undersigned.

Very respectfully,

/s/ F. Michael Swiek

F. Michael Swiek
Executive Director

APPENDIX

Table 1: Comparison of 1 dB C/N_0 degradation versus interference level affecting TTFF, derived from NASCTN plots

Rcvr Type	LTE Type	C/No Plot	TTFF Plot	DUT 7 (HPP) C/No/TTFF	DUT 8 (HPP) C/No/TTFF	DUT 9-C (HPP) C/No/TTFF	DUT 9-D (HPP) C/No/TTFF	DUT 10 (HPP) C/No/TTFF
HPP	DL	Fig 6.25; pg. 146	Fig 6.99; pg. 223	-65/-61.2	-70/-63.4	-60/-52.3	0/-1.5	-65-62.5
HPP	UL1	Fig 6.30; pg. 151	Fig 6.105; pg. 229	-45/-46.3	-55/-51.3	-50/-50.0	-35/-33.8	-55/-47.2
Rcvr Type	**LTE Type**	**C/No Plot**	**TTFF Plot**	**DUT 11-A (RTK) C/No/TTFF**	**DUT 11-B (RTK) C/No/TTFF**	**DUT 12-C (RTK) C/No/TTFF**	**DUT 12-D (RTK) C/No/TTFF**	
RTK	DL	Fig 6.50; pg. 171	Fig 6.107; pg. 231	-70/-67.0	N/A / N/A-24.6	-60/-54.3	-5/-1.3	
RTK	UL1	Fig 6.55; pg. 176	Fig 6.101; pg. 225	-60/-59.7	-20/-15.4	-50/-48.5	-40/-33.4	

To perform this comparison, the 1 dB C/N_0 values and the interference level at which TTFF increased for each test were drawn from Table 6.2, page 220, as well as estimated from the plots in the NASCTN report (as noted in the Table 1). The estimated points for each test are presented in the figures included as Table 3. Table 1 shows a summary of the 1 dB C/N0 values and the effect on TTFF performance.

Table 2: Tabular summary of NASCTN results for HPP and RTK receivers

		LTE DL 1526MHz – 1536 MHz No Lock [dBm]	LTE UL1 1627.5 MHz – 1637.5 MHz No Lock [dBm]
DUT 7	Nom	-34.8	-31.3
	Stress	-39.9	NA
DUT 8	Nom	-45.8	-33.8
	Stress	-57.4	-36.6
DUT 9-Ant C	Nom	NA	-29.6
	Stress	NA	-34.6
DUT 9-Ant D	Nom	NA	-13.8
	Stress	NA	NA
DUT 10	Nom	-37.8	-25.3
	Stress	-53.1	-33.2
DUT 11-Ant A	Nom	-54.3	-32.8
	Stress	-57.2	NA
DUT 11-Ant B	Nom	NA	NA
	Stress	NA	-8
DUT 12-Ant C	Nom	-39.9	-40.1
	Stress	No fix	No fix
DUT 12-Ant D	Nom	3.1	-15.3
	Stress	No fix	No fix

Table 3: Sources of data for Table 1

	HPP	RTK
Nominal GPS constellation	Figures 6.25, 6.26, 6.29, 6.30, 6.34, 6.35, 6.39,6.40	Figures 6.49, 6.50, 6.55, 6.56, 6.59, 6.60, 6.64, 6.65
Stressed GPS constellation	Figures 6.119, 6.120, 6.124, 6.125	Figures 6.129, 6.130, 6.134, 6.135