Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
LightSquared Request to Modify Its ATC Authorization	)	IB Docket No. 12-340
	)	
	)	IBFS File Nos. SAT-MOD-20151231-00090; SAT-MOD-20151231-00091; SES-MOD-20151231-00981; SAT-AMD-20180531-00044; SAT-AMD-20180531-00045
	)	
LightSquared Technical Working Group Report	)	IB Docket No. 11-109

COMMENTS OF TRIMBLE INC.

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July 9, 2018

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Trimble Inc. ("Trimble") submits these comments in response to Ligado Networks LLC's ("Ligado") amended applications for modification of its Mobile Satellite Service ("MSS") licenses.[1/] To the extent that, in evaluating the Modification Applications, the Commission addresses the standard for determining the potential for harmful interference to Global Positioning System ("GPS") and Global Navigation Satellite System ("GNSS") devices and applications, it should dismiss Ligado's calls for the rejection of the long-established interference protection criterion for GPS/GNSS receivers of a 1 dB decrease in the Carrier-to-Noise Power Density Ratio ("C/N_0") and the proposed alternative use of key performance indicators ("KPIs"). The 1dB standard has been consistently applied in a variety of spectrum contexts, but nowhere is it more appropriate than in the context of interference with GPS devices, which receive signals

1/ *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"); Ligado Networks LLC Amendment License Modification Applications, IBFS File Nos. SAT-AMD-20180531-00044 and SAT-AMD-20180531-00045 ("Amendment").

on earth below the noise floor and where every dB counts in many mission critical applications. Ligado's anecdotal attack provides no basis for abandoning this longstanding U.S. and international standard of harmful interference.

I. INTRODUCTION AND SUMMARY

Founded in 1978, Trimble is a leading provider of advanced positioning solutions using GPS, GNSS, their augmentations, laser, optical, and inertial technologies. Trimble integrates such technologies with application software, wireless communications, and services to provide complete commercial solutions and to make field and mobile workers in businesses and government significantly more productive. Its integrated solutions not only allow customers to collect, manage, and analyze complex information faster and easier, but also make them more efficient, effective, and profitable. Trimble's products are used in over 150 countries around the world, and it has offices in over 35 countries, along with a highly capable network of dealers and distribution partners. Trimble's portfolio includes over 1,200 unique patents and serves as the basis for the broadest array of offerings in the industry.

Ligado, through its amended Modification Applications, seeks authority to deploy a terrestrial network using MSS radiofrequency spectrum adjacent to long-established incumbent signals from the U.S. GPS as well as other international GNSS systems. As noted in Ligado's Modification Applications, Trimble and other manufacturers of GNSS equipment negotiated agreed-upon technical parameters for terrestrial use of some or all or Ligado's licensed MSS spectrum. In no cases, however, do these agreed-upon technical requirements constitute endorsement of Ligado's position on the appropriate standard for determining the potential for harmful interference to GNSS devices and applications.

Any assessment of the potential for harmful interference to GPS and GNSS devices that the Commission performs in processing the Modification Applications should make clear that –

in the absence of a consensus agreement, including with key government stakeholders, on specific technical parameters and conditions to address potential harmful interference – the Commission will use the 1 dB decrease in the C/N_0 metric. That is the metric that the GNSS industry, the Commission, and other federal agencies have used in various spectrum contexts for many years. This standard is amply supported by precedent and use in applicable technical standards, and it 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. Ligado's continued challenge to the standard and its use in the Department of Transportation's ("DoT") Adjacent Band Compatibility Assessment[2/] is unsupported and should be rejected.

In addition, the Commission should not endorse Ligado's assertions regarding either the Roberson and Associates ("RAA") testing[3/] or the National Advanced Spectrum and Communications Test Network ("NASCTN") report[4/] in assessing the amended Modification Applications. Both tests examined KPIs to assess whether a proposed power and out-of-band emission level would pose harm to GPS devices. Contrary to Ligado's contentions, however, KPIs do not provide a reliable basis for determining whether harmful interference has occurred before manifestation as a degraded KPI in particular use cases. In fact, the RAA testing and NASCTN report demonstrate the complexity and limitations of an approach focused on measuring impact on KPIs, and the NASCTN test results further provide support for use of the 1 dB standard.

2/ GLOBAL POSITIONING SYSTEM (GPS) ADJACENT BAND COMPATIBILITY ASSESSMENT, FINAL REPORT, UNITED STATES DEPARTMENT OF TRANSPORTATION (2018), https://www.transportation.gov/sites/dot.gov/files/docs/subdoc/186/dot-gps-adjacent-band-final-reportapril2018.pdf ("Adjacent Band Compatibility Assessment").

3/ *See* Ligado *Ex Parte,* IB Docket No. 11-109, Attachment A (filed May 11, 2016).

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

II. THE 1DB STANDARD IS THE APPROPRIATE METRIC FOR PROTECTING GPS AND GNSS RECEIVERS FROM HARMFUL INTERFERENCE

As the DoT recognized in its Adjacent Band Compatibility Assessment, "GPS has grown into a global utility." [5/] It is "an essential element of the worldwide economic infrastructure" used in applications ranging from "all modes of transportation to incorporation of GPS timing into the electric grid, communications networks, point of sale transactions, banking and finance, as well as applications of GPS for surveying, precision agriculture, weather forecasting, earthquake monitoring, and emergency response."[6/] Therefore, ensuring GPS and GNSS systems' continued availability and functionality is of utmost importance. Use of the 1 dB standard has thus far allowed GPS to be protected from harmful interference and all GNSS systems to serve a critical role in ensuring safety-of-life services and propelling economic growth.[7/]

Contrary to Ligado's assertions,[8/] the 1 dB standard is supported by well understood and critical aspects of GNSS engineering. To meet the needs of existing and future users, GPS and GNSS systems must 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.

5/ Adjacent Band Compatibility Assessment at 20.

6/ *Id*.

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 Demodulation*, in UNDERSTANDING GPS PRINCIPLES AND PRACTICE, 185 (C. Hegarty and E. Kaplan, eds., Artech House 2006). The US Air Force also recently published a technical paper defending the use of the 1 dB standard. *See* United States Air Force, *Background Paper of the Use of a 1 dB Decrease in C/N_0 as GPS Interference Protection Criterion*, https://www.gps.gov/spectrum/ABC/1dB-background-paper.pdf.

8/ *See* Amendment at 3 (referring to the DoT's use of 1 dB standard "empirically unsupported").

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, 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.

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

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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 [Terrain Awareness Warning Systems] 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.

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.

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.[12/] Other international bodies have also recognized the requirements for accuracy, integrity, continuity, and availability.[13/] Having well-established standards for measuring any

[11/] *See* WM. J. HUGHES TECHNICAL CENTER, REPORT #101 (2018), http://www.nstb.tc.faa.gov/reports/PAN101_0518.pdf.

[12/] *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.

[13/] *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, *available at* http://www.gsa.europa.eu/sites/default/files/calls_for_proposals/Annex%202.pdf (last visited May 23, 2016).

interference that can degrade these parameters is critical for continued innovation and development of GNSS technologies.

Critical engineering considerations associated with GNSS receivers highlight the potential for degradation in performance in the presence of interfering noise. As noted extensively in this docket, 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.[14/] 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.

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.[15/] So like BER and SNR, C/N_0 is a direct measurement of receiver performance, rather

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14/ *See* Betz, Hegarty, and Ward, *Satellite Signal Acquisition, Tracking, and Data Demodulation*, in UNDERSTANDING GPS PRINCIPLES AND PRACTICE, 247 (C. Hegarty and E. Kaplan, eds., Artech House 2006).

15/ 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.

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.[16/]

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.[17/] 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.[18/] 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.

16/ 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 . . . . ").

17/ 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.

18/ RTCA DO-327, Section D.1.5.

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 phase measurement. Lack of continuous carrier phase renders many high precision applications unavailable.[19/]

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

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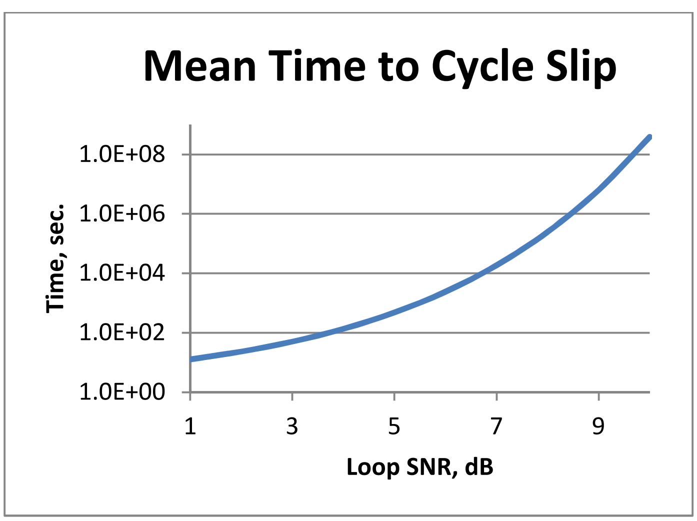
[19/] As shown in the chart in this footnote, the average time between cycle slips, or disruptions in carrier phase, which cause measurement reinitialization, decrease by an order of magnitude with a 1 dB reduction in loop SNR (which tracks directly with C/N_0). In other words, cycle slips occur 10 times 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).



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 therefore 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 ideal conditions) to cause degradation to the GPS system in excess of the 1 dB standard.

III. ALTERNATIVES TO THE 1 DB STANDARD ARE UNRELIABLE AND ADMINISTRATIVELY IMPRACTICAL FOR PROTECTING AGAINST HARMFUL INTERFERENCE

In its Amendment and Amendment cover letter, Ligado questions the 1 dB standard based on purported "empirical" analysis of KPIs using results of the NASCTN and RAA testing.[20] To the extent that the Commission addresses the value of the RAA testing or the NASCTN report, it should reject such uses of KPIs to measure interference to GNSS devices.

As Trimble and others have explained, position accuracy is not the only attribute on which GNSS users rely, and therefore KPIs simply cannot provide a reliable basis for determining whether harmful interference has occurred in particular use cases.[21] In fact, as has been previously detailed in this proceeding, the RAA testing and NASCTN report cited by Ligado demonstrate the complexity and limitations of an approach focused on measuring impact on KPIs.[22]

Use of KPIs would require that unique test scenarios be developed for each application. The volume of testing required across a host of subjective measures of user experience, multiplied by a plethora of test scenarios, and the vast amount of data produced would be staggering – and unlikely to demonstrate any universal trend or establishment of a measurement standard. Even if one were to assume – as Ligado appears to – that position accuracy is the only receiver output that matters, "[g]iven the myriad of GPS/GNSS applications requiring accuracy to support their mission applications ranging from tens of meters to millimeters, there is not a single 'accuracy degradation limit' that could be applied and trying to do so would be an intractable effort."[23] Without application of the 1 dB standard, it is not possible to evaluate and define whether "material degradation" across a wide range of applications actually occurs.

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[20] Amendment, Cover Letter; *see also* Amendment at 5.

[21] *See, e.g.,* GPS Innovation Alliance *Ex Parte*, IB Docket No. 11-109 (filed July 13, 2017); Comments of Trimble Navigation Limited, IB Docket No. 11-109, at 17-19 (filed May 23, 2016); Reply Comments of Trimble Navigation Limited, IB Docket No. 11-109, at 2-3 (filed June 21, 2016).

[22] *See, e.g.,* GPS Innovation Alliance *Ex Parte*, IB Docket No. 11-109 (filed July 13, 2017); Comments of Trimble Navigation Limited, IB Docket No. 11-109, at 17-19 (filed May 23, 2016); Reply Comments of Trimble Navigation Limited, IB Docket No. 11-109, at 2-3 (filed June 21, 2016).

[23] Adjacent Band Compatibility Assessment at 45.

Therefore, relying upon any proposal other than a C/N_0 standard for interference analysis and protection would devolve into an unmanageable quagmire of "picking winners and losers" based upon subjective definitions of "material degradation."

Accordingly, if the Commission addresses the value of the RAA testing or the NASCTN report in making its determination on the amended Modification Applications, it should reject the use of KPIs to measure interference to GNSS devices and confirm the necessity of the 1 dB standard as the only metric that effectively preserves all aspects of GPS receiver performance.

IV. CONCLUSIONS

The tremendous penetration of GPS and GPS-based technologies in U.S. infrastructure and across diverse industries has created widespread benefits. To innovate and lead the world in GNSS technology, GPS manufacturers rely on the 1 dB standard for determining the potential for harmful interference in product designs and testing. To the extent it address the issues in assessing the amended Modification Applications, the Commission should use the 1 dB standard and reject the use of KPIs to determine potential for harmful interference to GNSS devices.

Respectfully submitted,

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CERTIFICATE OF SERVICE

I, Radhika U. Bhat, hereby certify that on July 9, 2018 a copy of the foregoing Comments of Trimble Inc. was served by first-class mail, postage paid, on the following:

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