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-20120928-00160; SAT-MOD-20120928-00161; SAT-MOD-20101118-00239; SES-MOD-20121001-00872
	)	
LightSquared Technical Working Group Report	)	IB Docket No. 11-109
	)	
	)	DA 16-442

COMMENTS OF TRIMBLE NAVIGATION LIMITED

Russell H. Fox
Radhika Bhat

MINTZ, LEVIN, COHN, FERRIS, GLOVSKY AND POPEO, PC
701 Pennsylvania Ave., NW
Suite 900
Washington, DC 20004
(202) 434-7300

Counsel to Trimble Navigation Limited

James A. Kirkland
Vice President and General Counsel

TRIMBLE NAVIGATION LIMITED
935 Stewart Drive
Sunnyvale, CA 94085
(408) 481-8000

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Trimble Navigation Limited ("Trimble") submits these comments in response to the Public Notice[1/] released in the above-captioned proceeding by the Commission's International Bureau, Office of Engineering and Technology and Wireless Telecommunications Bureau seeking comment on applications for modification submitted by Ligado Networks LLC ("Ligado") to Mobile Satellite Service ("MSS") licenses.[2/] Trimble supports the adoption of the

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[1/] *See* Comment Sought on Ligado's Modification Applications, Public Notice, DA 16-442 (rel. Apr. 22, 2016) ("Public Notice").

[2/] *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 these comments, we use the term "Ligado" to refer to New LightSquared and its subsidiary LightSquared Subsidiary LLC. Trimble notes that Ligado submitted an extensive technical document intended to support certain of its contentions regarding its testing and the appropriate metrics for determining interference to GPS from terrestrial networks on May 11th. *See* Ligado *Ex Parte*, IB Dkt. No. 11-109 (filed May 11, 2016). Ligado stated that it intended that submission as part of the record in the Commission's consideration of its applications for modification. While Trimble makes certain preliminary comments regarding that additional material here, in light of the extensive nature of Ligado's submission, Trimble continues to review the submission and may further address it after that review is complete.

technical parameters and licensing conditions covering Ligado's licensed frequencies at 1627.5-1637.5 MHz and 1646.5-1656.5 MHz and the proposed limitations on operations in the 1545-1555 MHz band, all as specified in the Modification Applications, as an integrated package and as further detailed in Trimble's agreement with Ligado, (referred to herein as the "Agreed Licensing Conditions").[3/] As indicated in that agreement, Trimble does not yet support adoption of Ligado's proposals for use of the 1526-1536 MHz band as described in the Modification Applications, though discussions with Ligado regarding licensing conditions for that band are ongoing.

Taken as a whole, the Agreed Licensing Conditions represent a compromise which balances the competing public policy interests raised by Ligado's (and its predecessors') proposed use of their licensed spectrum. Given this compromise and balance, Trimble believes that it is in the public interest to grant the Modification Applications based upon the adoption of the Agreed Licensing Conditions as an integrated package.

I. INTRODUCTION AND SUMMARY

Founded in 1978, Trimble is a leading provider of advanced positioning solutions using Global Positioning System ("GPS"), Global Navigation Satellite Systems ("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

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[3/] *See* New LightSquared LLC *Ex Parte*, IB Dkt. Nos. 12-340, 11-109 (filed Feb. 3, 2016) (attaching a settlement agreement between Ligado and Trimble). This filing is incorporated by reference, and references to the Agreed Licensing Conditions shall refer to the totality of provisions in the agreement regarding Ligado's use of its licensed frequencies. For the avoidance of doubt, as stated above, the Agreed Licensing Conditions do not include licensing conditions for the 1526-1536 MHz band.

significantly more productive. Its integrated solutions not only allow customers to collect, manage, and analyze complex information faster and easier, but also makes them more efficient, effective, and profitable. Trimble's products are used in over 100 countries around the world, and it has offices in over 43 countries, along with a highly capable network of dealers and distribution partners. Trimble's portfolio includes over 1,100 unique patents and serves as the basis for the broadest array of offerings in the industry.

Ligado's proposed terrestrial network involves MSS radiofrequency spectrum adjacent to signals from the U.S. GPS, as well as other international GNSS systems.[4/] Given this spectral proximity, the introduction of a ubiquitous, relatively high-power terrestrial service such as Ligado's adjacent to faint space-to-earth signals from GPS and GNSS satellites presents complex and unique radiofrequency interference and electromagnetic compatibility challenges to ensure that high power signals do not cause interference to GPS/GNSS receivers, like those manufactured by Trimble. Accordingly, in order to balance the competing public policy interests raised by Ligado's (and its predecessors') proposed use of its licensed spectrum, Trimble entered into an agreement with Ligado, providing for the following Agreed Licensing Conditions: (1) adoption of the technical requirements set forth in the Modification Applications pertaining to terrestrial operations on frequencies from 1627.5 MHz upwards; (2) that Ligado will only use the 1545-1555 MHz band for satellite downlink purposes, and that it will not seek any terrestrial authorization for the 1537-1555 MHz band; and (3) removal by the Department of Transportation ("DOT") of consideration of Ligado's deployment of a terrestrial network

[4/] Ligado proposes use of segments of the frequencies in the MSS L-band (1525 MHz -1559 MHz and 1626.5 MHz -1660.5 MHz) for its terrestrial network, which are adjacent to the 1559 MHz -1610 MHz frequency band globally allocated to the Radionavigation Satellite Service ("RNSS") in which GNSS operates.

operating on frequencies 1627.5 MHz and above from the pending DOT Adjacent Band Compatibility Assessment, but continued consideration of terrestrial use of the 1526-1536 MHz band in the DOT process.[5/] In light of the compromise and balance struck by the settlement agreements, Trimble believes that it is in the public interest to grant the Modification Applications consistent with the Agreed Licensing Conditions as an integrated package.

Beyond the Agreed Licensing Conditions, there are policy issues that have been the subject of extensive controversy in prior filings in the instant proceeding where Ligado and Trimble, among others, have simply "agreed to disagree." One such issue is the appropriate standard for determining whether harmful interference exists in particular operating scenarios. Trimble's support for implementation of the Agreed Licensing Conditions does not constitute agreement with or endorsement of the assertions that Ligado has made regarding the correct metrics for determining the potential for harmful interference to GPS and other GNSS devices and applications. Since these assertions are included in the record of this proceeding, to ensure the completeness of the record, these comments will set forth in detail Trimble's position on this issue. Because of the complexity of this issue and the importance of the specific contexts in which it is considered, Trimble does not believe that resolution of this issue is necessary for the Commission to adopt the Agreed Licensing Conditions. The Commission continues to have a responsibility – beyond simply approving the applications under the parameters specified – to ensure that terrestrial operations do not cause harmful interference to GPS and other GNSS systems, and Trimble continues to believe that the established standard for determining the existence of harmful interference, whether there is a 1 dB increase in the noise floor, is the

[5/] *See* New LightSquared LLC *Ex Parte*, IB Dkt. Nos. 12-340, 11-109 (filed Feb. 3, 2016) (attaching a settlement agreement between Ligado and Trimble Navigation Ltd.).

appropriate standard where the affected parties have not reached cooperative agreements on appropriate licensing conditions.

II. GNSS PRODUCTS, SERVICES AND APPLICATIONS ARE FOUNDATIONAL IN OUR NATION'S ECONOMY AND REQUIRE VIGILANT PROTECTION

Over the last 30 years, GPS-enabled technology has become a critical and irreplaceable part of our national infrastructure, and becomes more deeply integrated with each passing year. Federal agencies, state and local governments, first responders, commercial and civilian aviation, agricultural and maritime interests, surveyors, construction workers, telecommunication service providers and everyday consumers all rely on GPS to manage infrastructure, to safely navigate our nation's roads, waterways and skies, and to conduct everyday work-related and recreational activities. The instant record is replete with evidence of GPS' importance to U.S. infrastructure. Among other examples:

- Aviation: Aviation interests led by the Aviation Spectrum Resources, Inc. ("ASRI") recently reaffirmed that "GPS service free from interference remains essential to the aviation industry, ensuring the safe and efficient operation of aircraft for both the flying public, and the nation's economy. Aviation GPS receivers are used by commercially operated aircraft globally to support navigation, position, traffic, weather, terrain awareness, system timing, and other functions."[6/]

- Telecommunications: The Alliance for Telecommunications Industry Solutions emphasized that the "U.S. telecommunications industry has deployed a large number of GPS receivers . . . which have a lifetime of more than 15 years, [and] are used for precision timing from fixed locations . . . The telecommunications industry is dependent on these receivers for precision time accuracy. The time standard, UTC, can only be widely distributed from GPS with today's technology. There is no other option. In addition, the telecom GPS timing systems are the enabling systems for other systems such as E911 triangulation and AGPS, which are used to find the location of wireless handsets."[7/]

[6/] *Ex Parte* Letter from Aviation Spectrum Resources, Inc. *et al.* to Marlene H. Dortch, Secretary, FCC, IB Dkt. No. 12-340, 3 (filed Dec. 14, 2015).

[7/] *Ex Parte* Letter from Alliance for Telecommunications Industry Solutions to Marlene H. Dortch, Secretary, FCC, IB. Docket Nos. 12-340, 11-09, 1 (filed Oct. 13, 2015).

- First Responders: The Association of Public-Safety Communications Officials-International, Inc. stated that "[m]any public safety agencies operate emergency communications on simulcast, trunked radio systems that depend upon GPS timing devices."[8/]

- Agriculture: A coalition of prominent agricultural interests explained that the "benefits of high precision GPS to U.S. agriculture are immense and diverse. By enabling farmers to make precise applications for planting, irrigation, and crop protection, GPS technology has been responsible for remarkable growth in productivity, farm income, and improved environmental sustainability."[9/]

- Construction/Surveying: The California Land Surveyors Association explained how "GPS technology has transformed the way we build and manage our infrastructure, adding a tremendous level of efficiency to the design, construction, and maintenance of roads, bridges, commercial properties, residential subdivisions, parks, farms, golf courses, etc."[10/]

- Maritime: The Boat Owners Association of the United States elaborated that the "GPS signal and the various devices that use it have become an integral part of boating. Beyond simple position information, GPS has been incorporated into the functions of many important safety and utility devices used by boaters."[11/]

The tremendous penetration of GPS and GPS-based technologies in U.S. infrastructure and across diverse industries creates tangible, large-scale and widespread economic benefits. A Boston Consulting Group study commissioned by Google found that in 2011 alone the U.S. geospatial industry generated approximately $73 billion in revenues.[12/] Moreover, geospatial

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8/ Comments of The Association of Public-Safety Communications Officials-International, Inc., IB. Docket No. 11-09 (filed Aug. 1, 2011).

9/ Comments of American Farm Bureau Federation *et al.,* IB. Docket No. 11-09, 1 (filed Mar. 14, 2012).

10/ Letter from California Land Surveyors Association to Marlene H. Dortch, Secretary, FCC, IB. Docket No. 11-09 (filed Aug. 5, 2011).

11/ Comments of the Boat Owners Association of the United States, IB Docket No. 11-109 (filed Mar. 14, 2012).

12/ *See Putting the U.S. Geospatial Services Industry On the Map*, THE BOSTON CONSULTING GROUP, at 3 (Dec. 2012), *available at* http://www.valueoftheweb.com/ ("Boston Consulting Study"). Similarly, a study of the economic benefits of GPS in the United States requested by the National Space-

services deliver efficiency gains in the rest of the U.S. economy, driving $1.6 trillion in revenue and $1.4 trillion of cost savings, which is 15 to 20 times the size of the geospatial services industry itself.[13/] So many systems and technologies in the U.S. economy require location information, in fact, that the value of GPS has become as difficult to assess as the value of utilities like electricity and telephones.[14/] In addition, the U.S. geospatial industry directly provides at least 500,000 high-wage jobs, and an estimated 5.3 million workers (over 4% of the U.S. workforce) rely on GPS technology daily.[15/]

The FAA estimates the cumulative benefits of its "NextGen" navigation architecture, which relies on GPS technology, to be "$23 billion through 2018; and by 2030, the cumulative benefits grow to $123 billion."[16/] In addition, the FAA expects NextGen to "reduce CO2 emissions by 64 million tons" by 2030.[17/] Research conducted by Oxera Consulting estimates that use of GPS and the mapping and navigation technologies which depend on it has reduced travel time by over 1.1 billion hours per year worldwide by getting people to their destinations more efficiently, saving U.S. consumers $5.5 billion.[18/]

Based Positioning, Navigation & Timing Executive Committee placed the value of GPS's economic benefits at approximately $68.7 billion, while admitting that this number was an underestimate due to data limitations. *See* Irv Leveson, The Economic Value of GPS: Preliminary Assessment, Presentation to the National Space-Based Positioning, Navigation and Timing Advisory Board Meeting (Jun. 11, 2015), *available at* http://www.gps.gov/governance/advisory/meetings/2015-06/leveson.pdf.

13/ Boston Consulting Study at 3.

14/ *See* GREG MILNER, PINPOINT 100-101 (W.W. Norton & Co. 2016).

15/ Boston Consulting Study at 3.

16/ Federal Aviation Administration, Lightsquared Aviation Impacts Paper (Jul. 12, 2011) at 2 (on file with the Executive Office of the President's Space-Based Positioning, Navigation and Timing Executive Committee's National Coordination Office Director).

17/ *Id*. at 1.

18/ *What is the Economic Impact of Geo Services?,* OXERA CONSULTING LTD., at 18-19 (Jan. 2013), *available at* http://www.valueoftheweb.com/.

In agriculture, "use of precision GPS technology, at [2011] adoption rates of 60%, increased U.S. farm revenue by approximately $20 billion per year, the equivalent of nearly 12 percent of total annual production . . . [and] if adoption rates of GPS had been at full 100% utilization, the growth in farm revenue would have been nearly $30 billion."[19/] GPS-based technologies are also likely to provide significant economic benefits by facilitating rapidly expanding industry sectors. For example, the economic benefits from GPS-enabled Unmanned Aircraft Systems between 2015 and 2025 are expected to reach $82 billion and create 100,000 new jobs,[20/] and it is estimated that "location based services" via smart phones and portable devices will deliver $700 billion in economic value to consumers and businesses by 2020.[21/]

III. APPROVAL OF THE MODIFICATION APPLICATIONS SHOULD BE NARROWLY TAILORED TO AVOID POLICY CHANGES OR PREMATURE RESOLUTION OF POLICY ISSUES WITH BROADER APPLICABILITY[22/]

The licensing conditions agreed upon by Trimble and Ligado do not include agreement on the generally applicable standard for determining whether harmful interference exists, because the parties were able to reach agreement on licensing conditions without resolving this

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[19/] Comments of American Farm Bureau Federation *et al.,* IB. Docket No. 11-09, 1 (filed Mar. 14, 2012).

[20/] *The Economic Impact of Unmanned Aircraft Systems Integration in the United States*, ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS INTERNATIONAL, at 2-3 (Mar. 2013), *available at* http://www.auvsi.org/auvsiresources/economicreport.

[21/] *Big data: The next frontier for innovation, competition, and productivity*, MCKINSEY GLOBAL INSTITUTE, at 93 (Jun. 2011), *available at* http://www.mckinsey.com/business-functions/business-technology/our-insights/big-data-the-next-frontier-for-innovation.

[22/] While the technical discussions in this section were developed based upon the collaborative efforts of members of the GPS Innovation Alliance ("GPSIA") and GPSIA members have discussed drafts of the material in this section with each other, the different members of GPSIA have different agreements with Ligado regarding the applicability of the 1 dB standard and will express different positions based on their individual agreements. The use of any common technical content in comments in this proceeding should not be interpreted as concurrence by specific GPSIA members in the positions of other GPSIA members on this issue.

issue. Trimble continues to disagree with Ligado's suggestions regarding the metrics used to assess whether harmful interference has occurred in contexts which have not been addressed through Trimble's agreement with Ligado.[23/] Trimble believes 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 NTIA have used in various contexts for many years – whether there is a 1 dB decrease in the Carrier-to-Noise Power Density Ratio ("C/N_0").[24/] Use of measurements of GNSS performance based on user-perception or user-experience would produce results as numerous and varied as the domestic and worldwide uses of GNSS. Evaluating GNSS interference only by reference to such anecdotally-driven standards would fail to account for the need to ensure accuracy, integrity, continuity, and availability of the GNSS signal. 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.[25/]

[23/] *See, e.g.*, Ligado Networks LLC *Ex Parte*, IB Docket Nos. 11-109, 12-340 (filed Feb. 24, 2016); Ligado *Ex Parte*, IB Dkt. No. 11-109, Attachment A (filed May 11, 2016).

[24/] For ease of reference, this standard is referred to as the "1 dB standard."

[25/] "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).

A. Four Aspects of GNSS Performance Are Critical in Existing and Emerging Applications

As discussed above, GPS and GNSS systems have become ubiquitous in the U.S. and world economies, and ensuring their continued availability and functionality is a top domestic policy goal. 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.[26/]

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.[27/] Volcanologists use GPS to detect and measure how the ground near a volcano inflates and moves as the underground magma expands, another endeavor in which accuracy is essential. Survey GNSS, precision agriculture, and intelligent

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[26/] "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, *available at* http://www.navcen.uscg.gov/pdf/2008_Federal_Radionavigation_Plan.pdf

[27/] 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).

transportation systems could not begin 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 and 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. 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 close to terrain, as mentioned above, 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. Lack of availability would also wreak havoc with the timing functions GNSS supplies to the banking industry; "smart cars" would need to stop in their tracks; and a precision-enabled tractor would have to suspend operations because the human operator could

not steer to the required accuracy. Data show that GPS, as it currently functions, meets Service Availability requirements nearly 100% of the time.[28/]

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.[29/]

The significant and ongoing investment in new GNSS satellites, not only by the U.S. but by other nations, demonstrates the demand for GNSS-based technologies across all applications. The GNSS industry expects that the four aspects of performance noted above will continue to guide the future development of services and equipment. The industry is therefore highly motivated to continually improve the accuracy, integrity, availability, and continuity of signals.

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

[29/] *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.

Having well-established standards for measuring any interference that can degrade these parameters is essential to such innovation and development.

B. Changes in Received C/N_0 Are the Most Useful Indicators for Determining the Effect on All Four Performance Attributes

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, and effective multipath rejection also requires wideband signals. In addition, unlike communications systems, which operate above the noise floor, spread spectrum GPS signals are below the thermal noise floor when they are received.[30/] 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 administrators 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. As Hegarty notes, "[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."[31/] So like BER and SNR, it is a direct measurement of receiver performance rather than a

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30/ *See* UNDERSTANDING GPS PRINCIPLES AND PRACTICE, *supra* note 25, at 247.

31/ *Id*. at 233.

downstream measurement of use-case dependent parameters (such as position error) and is therefore the most appropriate parameter for consideration in an interference analysis.

C/N_0 is measured by receivers at frequent periodic intervals such as 1 Hz, 5 Hz, or 10 Hz. Momentary fluctuations in C/N_0 yield insight into receiver function that otherwise may be masked by averaging. Use of C/N_0 as an interference metric 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.[32/]

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 signal 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.[33/]

[32/] 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 . . . . ").

[33/] "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 1 215-1 400 MHz*, INTERNATIONAL TELECOMMUNICATION UNION, at p. 8 Section 3 (2015).

C. Establishing Harmful Interference as a 1 dB Decrease in C/N_0 Has Become the Universally Employed Metric Because It Yields Meaningful Results Across a Variety of Test Configurations and Across All Four Performance Attributes

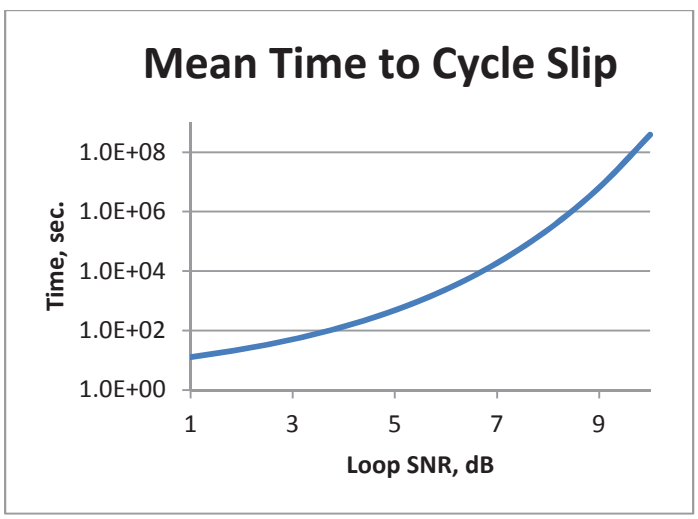
Not only does use of C/N_0 have great utility as an objective interference measure, but a particular standard – a 1 dB decrease in C/N_0 – has become a long-utilized and well-recognized interference metric in the GNSS industry because of its reliability as a comprehensive metric. A decrease of 1 dB in C/N_0 has the effect of 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. For example, a 1 dB reduction in C/N_0 will cause 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.[34/]

It is important to remember, though, that degradation may occur before the point at which there has been a 1 dB reduction in C/N_0, or 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 ideal conditions) to cause degradation to the GPS system in excess of the 1 dB standard.

34/ 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 tracts 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).



D. Alternative Proposals for Measuring Harmful Interference Are Unreliable and Administratively Impractical

In relying on GNSS, users require all four attributes – accuracy, integrity, continuity, and availability – not just position accuracy, as has been suggested by some.[35/] For instance, in some applications, the primary receiver output may not even be position, but rather time, velocity, acceleration, or some other characteristic. One example is the banking industry in which GNSS serves as a key source of timing information, allowing the industry to keep track of electronic payments, withdrawals, and transfers. Data provided by Roberson does not address these parameters,[36/] and the effect of interference on these receiver outputs has not been addressed, or even considered, in terms of what is "material interference." Utilization of a 1 dB C/N_0 metric provides a standard measure and removes the need to test for any of these other application-specific characteristics.

[35/] *See, e.g.*, New LightSquared LLC *Ex Parte*, IB Dkt. Nos. 12-340, 11-109 (filed Feb. 10, 2016).

[36/] As noted earlier, Trimble is still reviewing Ligado's May 11, 2016 submission, which includes material from Roberson and Associations, LLC. *See* Ligado *Ex Parte*, IB Dkt. No. 11-109 (filed May 11, 2016). As a preliminary matter, Trimble observes that the tests described in that material yielded a partial dataset for a limited number of KPIs applied to an even more limited selection of receivers. Notably, despite its oft-repeated declaration of "no impact," the report fails to identify objective pass/fail thresholds for the KPIs Roberson measured. Further, the report seems to selectively ignore KPIs that were measured but then proved problematic for its declaration of "no impact." For example, the data files provided suggest that there were multiple instances in which the receiver was unable to maintain lock on the WAAS signal. Despite the fact that WAAS failure has presented an obstacle to Ligado signals in the past, this failure seems to have been omitted from the Roberson test report (or in one case, dismissed with a footnote, again without objective pass/fail criteria). Moreover, the data in the filing available on the FCC's website are veiled by an unexplained 3-minute averaging window which masks the kinds of momentary deviations in position, timing, acceleration, and C/N_0 that are critical to many of the applications mentioned above (*e.g.*, aviation, banking, earthquake fault monitoring, etc.). Finally, Roberson omitted testing of Trimble's high precision receivers while functioning in high precision mode, and was thereby unable to assess the potential interference from terrestrial networks operating in the 1516-1526 MHz band on high precision GNSS receiver performance.

Without application of a 1 dB decrease in C/N_0 standard, it would not be possible to evaluate and define whether "material degradation" across a wide range of applications had actually occurred – not to mention what constitutes "material." Further, individual, unique test scenarios would need to be developed for each application. For example, certified aviation devices would require unique test scenarios for precision landing in situations in which the receiver generally has an unobstructed view of the open sky. Conversely, intelligent transportation systems would likely need a test scenario that takes into account an obstructed view of the sky and impairments from buildings and terrain. 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 administratively staggering – and unlikely to demonstrate any universal trend or establishment of a measurement standard.

Even if the data from the thousands of very different use cases could somehow be accumulated, organized, and reviewed, assessing appropriate lines and determining relevant definitions would represent, quite simply, an impossible task. For instance, there is no readily applicable or other universally measurable definition of when degradation is "material." Moreover, if one use case requires lower levels of adjacent band interference than another before "material degradation" occurs, who decides which use case is more important? Relying upon any proposal other than a C/N_0 standard for interference analysis and protection will devolve into an unmanageable quagmire of "picking winners and losers" based upon subjective definitions of "material degradation," rather than a universally accepted, objective and physical measure of C/N_0 – the 1 dB standard.

To innovate, design for the future, and continue to lead the world in GNSS technology, U.S. manufacturers need a universal, consistent, and quantifiable metric to incorporate into their product designs and testing.

IV. THE COMMISSION SHOULD ENSURE PROTECTION OF INTERNATIONAL GNSS

The Public Notice asks whether there are interference concerns for wideband GPS signals transmitted within 1560-1591 MHz that are left unresolved by the agreements.[37/] Trimble notes that this portion of the notice refers only to the U.S. GPS frequency allocation, and does not expressly recognize the need for the FCC to provide interference protection to devices utilizing spectrum allocated internationally for GNSS which is outside of the 1560-1591 MHz U.S. allocation, including spectrum utilized by other GNSS systems – such as the Global Orbiting Navigation Satellite System ("GLONASS"), Galileo, and BeiDou.

While receipt of transmissions from foreign constellations using the full 1559-1610 MHz band may be subject to additional inter-governmental processes,[38/] the Commission should not compromise or undermine use of those systems by permitting operations that will cause them interference. The public interest will best be served by allowing devices to receive signals from multiple GNSS constellations. For instance, multi-constellation GNSS technologies better meet the 911 location accuracy needs of the public and the public safety community, as these technologies offer "dramatic improvements in both outdoor and, critically, indoor location

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37/ *See* Public Notice at 8.

38/ *See National Telecommunications And Information Administration Provides Information Concerning Executive Branch Recommendations for Waiver of Part 25 Rules Concerning Licensing of Receive-Only Earth Stations Operating with Non-U.S. Radionavigation Satellites*, Public Notice, 26 FCC Rcd. 3867 (2011).

performance."[39] In addition, among other benefits, multi-constellation receivers offer lessened signal acquisition time, reduced problems due to obstructions like buildings and foliage, improved dilution of precision, and better continuity in the event of signal blockage.[40] Therefore, the Commission should not prevent the public from realizing the benefits of multi-constellation operations in the future by failing to protect them today.

Moreover, protection of receivers using other constellations is consistent with the United States' international obligations. Significantly, the International Telecommunication Unions Radio Regulations allocate the 1559-1610 MHz band internationally for GNSS use.[41] As a signatory to the Constitution and the Convention of the International Telecommunication Union, the United States is obligated to take the steps necessary to observe the Radio Regulations.[42]

Consistent with the need for worldwide protection from interference from non-GNSS systems, the United States has worked to ensure the utility of the various GNSS systems by entering into numerous cooperative relationships with other countries and international

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[39] Letter from Telford E. Forgety, III, NENA: The 9-1-1 Association, to Marlene H. Dortch, Secretary, FCC, PS Dkt. No. 07-114, 3 (Sep. 25, 2013) ("[H]igh-precision multichannel and multi-constellation GNSS receivers are becoming commonplace in even mid-range devices. At the same time, new satellite- and ground-based positioning systems are coming on line, with GALILEO, COMPASS, Boeing Timing & Navigation, and NextNav networks all offering dramatic improvements in both outdoor and, critically, indoor location performance.").

[40] *See Multi-Constellation and Multi-Frequency*, NOVATEL INC. (last accessed May 11, 2016), http://www.novatel.com/an-introduction-to-gnss/chapter-5-resolving-errors/multi-constellation-and-multi-frequency/.

[41] *See* International Telecommunication Unions Radio Regulations, art. 5 (2012), http://www.itu.int/dms_pub/itu-s/oth/02/02/S02020000244501PDFE.PDF.

[42] *See*, Constitution and the Convention of the International Telecommunication Union, art. 5-6 (2014), http://www.itu.int/dms_pub/itu-s/oth/02/09/S02090000155201PDFE.PDF. The United States has not ratified the most recent amendments to the Constitution and the Convention of the International Telecommunication Union, however, the previously ratified text and amendments include the same obligation to observe the Radio Regulations. *See* Constitution and the Convention of the International Telecommunication Union, art. 5-6 (2006), *available at* http://www.itu.int/dms_pub/itu-s/oth/02/09/S02090000105201PDFE.PDF.

organizations in order to promote GNSS system radiofrequency compatibility and interoperability.[43/] The United States has similarly urged continued international support for the recommendations of the International Committee on GNSS working groups that promote the implementation of protection measures for GNSS operations around the world.[44/] The U.S. GPS industry has also been active with regard to standards setting proceedings in other countries, advocating against potential interference to GNSS systems abroad.[45/] In order to aid all of these efforts and encourage reciprocity, the U.S. should take a similar approach to foreign constellations and consider appropriate protections for them as a part of this proceeding.

V. CONCLUSION

Trimble supports the adoption of the Agreed Licensing Conditions covering Ligado's licensed frequencies at 1627.5-1637.5 MHz and 1646.5-1656.5 MHz and the proposed limitations on operations in the 1545-1555 MHz band, all as specified in the Modification Applications and as further detailed in Trimble's agreement with Ligado, as an integrated package. Trimble does not currently support adoption of Ligado's proposals for use of the 1526-1536 MHz band as described in the Modification Applications, though discussions with Ligado

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43/ *See, e.g., International Cooperation*, GPS.gov (last modified Mar. 10, 2016), http://www.gps.gov/policy/cooperation/ (providing information about the United States' various cooperative relationships and agreements, such as the 2004 GPS-Galileo Agreement between the United States and the European Union and the 2004 Joint Statement establishing cooperation between the United States and Russia).

44/ *See* Statement of Margaret Kieffer, United States Representative, to the United Nations Committee on the Peaceful Uses of Outer Space (Feb. 2015), http://www.gps.gov/news/2015/02/COPUOS/.

45/ *See, e.g.,* Proposed European (CEPT) Regulation Would Allow Harmful Interferers Into An ARNS & RNSS Radiofrequency Band Within Europe, Presentation to the Position, Navigation, and Timing Advisory Board, GPS Innovation Alliance (June 3, 2014) (encouraging government agencies to address regulations in Europe that would cause harmful interference to GNSS systems), http://www.gpsalliance.org/docs/GPSIA_Presentation_to_PNT_Board.pdf.

regarding licensing conditions for that band are ongoing. Taken as a whole, the Agreed Licensing Conditions represent a compromise which balances the competing public policy interests raised by Ligado's (and its predecessors') proposed use of their licensed spectrum. Given this compromise and balance, Trimble believes that it is in the public interest to grant the Modification Applications as set forth herein. In taking such action, the Commission should avoid adopting criteria for determining whether harmful interference exists other than the established 1 dB standard.

Respectfully Submitted,

/s/ James A. Kirkland

James A. Kirkland
Vice President and General Counsel

TRIMBLE NAVIGATION LIMITED
935 Stewart Drive
Sunnyvale, CA 94085
(408) 481-8000

Russell H. Fox
Radhika Bhat

MINTZ, LEVIN, COHN, FERRIS, GLOVSKY AND POPEO, PC
701 Pennsylvania Ave., NW
Suite 900
Washington, DC 20004
(202) 434-7300

Counsel to Trimble Navigation Limited

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