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Submitted Electronically

June 28, 2016

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

Re: IB Docket Nos. 12-340 and 11-109; and IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091; DA 16-442

Dear Ms. Dortch:

Garmin International, Inc. hereby submits revised reply comments in the above-referenced rulemaking dockets, which it requests be considered in lieu of the reply comments that it submitted on June 21, 2016. Ligado Networks, LLC consents to this submission

Very truly yours,

M. Anne Swanson
Counsel to Garmin International, Inc.

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	IB Docket No. 12-340
	)	
LightSquared Request to Modify Its ATC Authorization	)	IBFS File Nos. SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SAT-MOD-20151231-00090; SAT-MOD-20151231-00091; SAT-MOD-20151231-00981
	)	
LightSquared Technical Working Group Report	)	IB Docket No. 11-109
	)	
	)	DA 16-442

REPLY COMMENTS OF GARMIN INTERNATIONAL, INC.

GARMIN INTERNATIONAL, INC.

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Dated: June 21, 2016

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SUMMARY

Garmin does not oppose grant of the Ligado Modification Applications, including specified power limits and out-of-band emissions limits, consistent with its settlement agreement with Ligado.

Garmin cautions that its position with respect to the Modification Applications must not be interpreted as its acquiescence in or support for a metric other than the internationally accepted and applied 1 dB metric. Similarly, the FCC must give serious attention to crafting a condition for the Ligado authorizations that adequately considers concerns raised by the FAA and RTCA.

Garmin remains a staunch supporter of application of the 1 dB standard to measure interference. Use of any alternative measure based on user-experience and essentially anecdotal testing will fail to consider the vast number of devices, uses, and environments in which devices are deployed; such an approach is an inadequate substitute. Moreover, as discussed in detail in Garmin's comments, a technical report that Ligado supplies actually corroborates the difficulties in using myriad key performance indicators or KPIs and highlights the need for a single metric.

Garmin finds very promising Ligado's continued willingness to work with the FAA and RTCA on addressing potential interference to certified aviation GPS devices from Ligado's base stations operating at 1526-1536 MHz. The power level proposed for base stations appears to be similar to levels already shown to cause concern in RTCA analyses. Ligado's willingness to reduce the power level further will be important, and the FAA and FCC must work diligently to find an effective solution as well as straightforward approaches for any resulting changes affecting the aviation community. The FAA and FCC also need to consider cross-agency enforcement mechanisms for all affected stakeholders to ensure continued aviation safety.

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	)	
	)	DA 16-442

REPLY COMMENTS OF GARMIN INTERNATIONAL, INC.

Garmin International, Inc. ("Garmin"), by its attorneys, hereby submits its reply comments regarding certain of the submissions already made in the above-captioned docket in response to the Public Notice released on April 22, 2016.[1] As discussed below, Garmin believes that the modification applications that Ligado submitted on December 31, 2015 ("Modification Applications") reflect improvements over its predecessor's previous technical proposals. As also discussed below, in evaluating potential interference to GPS that may result from grant of the Modification Applications, the FCC should apply a metric based on a 1 dB decrease in the Carrier-to-Noise Power Density Radio ("C/N_0"). At the same time, Garmin urges the FCC to carefully craft any conditions it may impose related to protection of certified aviation GPS devices from interference caused by Ligado's use of its downlink spectrum (1526 to 1536 MHz)

[1] *See* "Comment Sought on Ligado's Modification Applications," *FCC Public Notice*, DA 16-442 (rel. Apr. 22, 2016) ("Public Notice"). In these comments, Garmin uses the term "Ligado" to refer also to Ligado's predecessors.

to ensure that Federal Aviation Administration ("FAA") and RTCA, Inc. input is fully reflected and that implementation of any conditions will be straightforward, so as to avoid stymying innovation and, more importantly, jeopardizing aviation safety.

I. INTRODUCTION

Garmin, as the result of a settlement agreement that it reached with Ligado's predecessor in December 2015, does not object to grant of the Modification Applications, including specified power limits and out-of-band ("OOBE") limits, consistent with its settlement with Ligado.[2] As also provided in the settlement agreement and noted in Garmin's initial comments in this proceeding, the Commission should utilize a metric based on a 1 dB decrease in C/N_0 to address any interference concerns related to GPS. Finally, consistent with its Ligado settlement agreement and as indicated in its initial comments, Garmin's submissions should not be interpreted as an endorsement of Ligado's proposed network or an indication of resolution of all issues regarding certified aviation devices that may be raised by establishment of Ligado's terrestrial network under the parameters proposed in its Modification Applications.

Garmin entered into a settlement agreement with Ligado to terminate a lawsuit that Ligado had brought against Garmin and two other GPS manufacturers. The settlement agreement sets forth power and OOBE levels related to assuring Ligado's new network will not cause interference to GPS devices manufactured by Garmin. Although not objecting to Ligado's Modification Applications, Garmin wants to clarify, as it has previously noted on the record, that its own narrow settlement agreement with Ligado reflects Garmin's judgment only that, notwithstanding interference to existing Garmin receivers, it will be able to address interference

[2] *See* Letter of Gerard J. Waldron to Marlene H. Dortch, IB Dkt. Nos. 12-340 *et al.*, filed Dec. 17, 2015, *et al.*, transmitting "Settlement Agreement and Releases, by and between Garmin International, Inc. and New LightSquared LLC and LightSquared Subsidiary LLC."

issues in its technology plan for future Garmin receivers (putting aside certified aviation devices) assuming the Ligado network complies with the technical and other terms set forth in the settlement agreement.[3]

Evaluation and testing during Garmin's transition process under the settlement agreement will need to be guided by a standard metric for assessing interference to its devices, a reliable and comprehensive measure that will work consistently for Garmin's myriad devices and across their infinite use cases. As discussed in more detail below, Garmin submits that the 1 dB standard is the only reliable and comprehensive metric that the GPS industry, Ligado, and the Commission should apply in interference analysis, particularly given its widely accepted use throughout the world and the nation's interest in having GPS remain the world's preeminent geo-location service, particularly in aviation safety matters.

II. A UNIVERSAL METRIC IS NEEDED TO ASSESS PERFORMANCE

In its comments, Ligado disputes the appropriateness and utility of a universal metric – specifically, a 1 dB decrease in C/N_0 – in this proceeding. Moreover, it disputes whether a selection of a metric even needs to be made in this context.[4]

The use of key performance indicators as an alternative to the 1 dB metric needs to be put in perspective. Under a user-centric approach, evaluating interference concerns and determining if GPS devices will function in ordinary and critical situations requires the testing of virtually every single potentially affected device across all its various use cases – meaning both the

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[3] *See* Letter of M. Anne Swanson to Marlene H. Dortch, IB Dkt. Nos. 12-340, *et al.*, Mar. 9, 2016, at 1-2. Garmin's settlement agreement with Ligado is a matter of public record at the FCC. Ligado also states that its recent coordination agreement with the Aerospace and Flight Test Radio Coordinating Council "bolster[s]" the conclusion that "Ligado's proposed terrestrial deployment will not harm GPS devices." Ligado Reply Comments at 13-14. Garmin has been unable to locate that agreement in the FCC's public record.

[4] Ligado Reply Comments at 11-14.

functions for which the devices are used and the environments in which they are deployed. Ligado and its consultants have devoted a great deal of time and effort to doing that, but they have only begun to scratch the surface regarding potential interference to GPS. Lacking the resources and the time to undertake such a gargantuan measurement project, the FCC and other regulators need a common metric that works across all devices, all their uses, and all the environments in which they are deployed to give the agency, GPS manufacturers, and new broadband providers a way to comprehensively evaluate the effect of new communications services on GPS and not endanger the critical reliance that American consumers and industry place on it.

The Commission must affirm the universally accepted 1 dB standard if it is to properly assess interference. *First,* the publicly filed Garmin-Ligado agreement provides, if required, for specified periods with reduced power levels to permit time for design of hardened receivers that will be able to tolerate interference at the levels specified in the settlement agreements. That design change process is ongoing at Garmin and is itself based on ensuring that GPS products are not degraded by more than 1 dB C/No in the presence of Ligado signals. Garmin does not oppose the Ligado Modification Applications precisely <u>because</u>, speaking only for Garmin's devices, the technical parameters to which it agreed in the settlement agreement were based on its own testing using the 1 dB metric.

Second, the Garmin settlement agreement expressly notes that it is not "an endorsement by Garmin of any technical, operational, policy, regulatory, or other matter regarding LightSquared's network . . . ."[5] Garmin's agreement only concerns its own devices and

[5] *See* Settlement Agreement, *supra*, note 2, at Section 12.

obviously does not represent industry consensus with respect to other devices. It simply was not negotiated to protect other incumbent users by preventing harmful interference to their devices.

As Ligado and the Sturza Report assert, and Garmin has never disputed, a variety of factors affect receiver C/N_0.[6] In fact, as the detailed descriptions in the Sturza Report show, these other factors are often discussed and understood in terms of their contribution to C/N_0 degradation. (This use of C/N_0 alone demonstrates the relevancy of the metric.)[7]

All systems – GPS or otherwise – require a framework for assessing the effects of various adjacent services, terrain, and propagation conditions. No alternative KPI proposal to date allows system designers at Garmin to conduct such analyses, nor can Garmin conceive of a single KPI that could meet that need. Just like many other technical measurements and metrics that have met the test of time and become internationally accepted and applied, the 1 dB metric is the only measurement that allows this type of comprehensive evaluation for GNSS.

It is also incorrect to assume that, because other independent error sources exist within the GPS system, C/N_0 is not the most important factor to consider. Ligado notes errors "caused predominately by elements completely independent of C/N_0," such as Signal-in-Space ("SIS") errors from satellite and ground control, atmospheric delays, and multipath, attempting to paint a picture of GPS performance dominated by errors from such factors.[8] The history of GPS, however, is one of continual innovation with GPS manufacturers overcoming such errors time and again, designing their products to compensate for such factors. Indeed, the Sturza Report acknowledges that the technological innovations that have been devised by the GPS industry to

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[6] Ligado Reply Comments at 12; "Changes in C/N_0 are Not a Reliable Indicator of KPI Impact," Attachment B to Ligado Reply Comments, ("Sturza Report") at 1.

[7] *See, e.g.*, Sturza Report, at Table 1.

[8] Ligado Reply Comments at 12-13.

overcome these errors are themselves sensitive to changes in C/N_0. The Report specifically "note[s] that augmented GPS services, such as DGPS, NDGPS, WAAS, LAAS, and CORS reduce the contributions of the SIS errors. This makes these services more sensitive to C/N_0 degradation."[9] These augmentation services also reduce the contribution of atmospheric delays.

In several instances, the Sturza Report actually corroborates the difficulties in using various alternative KPIs to assess interference and, thus, supports the use of 1 dB as the appropriate interference metric. *First*, the wide variety of environmental factors that the Sturza Report cites as affecting the GPS system helps make the case that measuring through a 1 dB standard is superior because various KPIs would require careful design of innumerable scenarios to ensure that the plethora of GPS use cases are properly included and measured. The Sturza Report also notes the importance of utilizing KPIs that correlate with position, velocity, and time outputs[10] – thus tripling the analysis needed for many GPS devices.

Second, the Sturza Report notes the differences between tracking and acquiring GPS signals, even discussing a few specific receivers and their sensitivity limits in an attempt to show why a 1 dB drop in C/N_0 is insignificant to receiver performance.[11] Sturza overlooks the fact, however, that receivers operating at these extreme limits of receiver sensitivity typically do not provide the kind of information consumers have come to expect,[12] and certainly are incapable of meeting certified aviation requirements for safety-of-life services.[13] In fact, when considering

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[9] Sturza Report at 17.

[10] Sturza Report at 1.

[11] Sturza Report at 6-7.

[12] Note, for example, that although the Sturza Report utilizes tracking thresholds of less than 10 dB-Hz to further its argument, these operating points are not even graphed in the report likely because they are essentially unusable. *See* Sturza Report, Figure 6, pg. 12.

[13] Certified aviation receivers raise a host of unique issues related to tracking and acquisition sensitivity. Unlike some GPS devices that can acquire a GPS signal and then proceed to track *(...cont'd)*

high-sensitivity receivers, it is critical to understand that changes in C/N_0 become even more significant at the extreme operating points considered by Sturza.[14] Conclusions based on such a limited comparison of receivers and selective data hardly prove Sturza's point; rather, the associated difficulties discussed herein demonstrate that C/N_0 remains the best metric for assessing interference to GPS receivers.

Third, the Sturza Report suggests that another KPI – time to first fix or "TTFF" – is independent of C/N_0,[15] a statement with which Garmin cannot agree. As a preliminary matter, if the received C/N_0 level is not above the receiver acquisition threshold, no ephemeris data (certain orbital and clock information data from each satellite that is necessary to compute a fix) can be processed – in other words, the receiver will never get a fix. Signal continuity is particularly critical in the ephemeris acquisition stage of receiver operation; sufficient C/N_0 levels are a prerequisite for even running a TTFF test in the first place. Because the ephemeris data are transmitted periodically, if the receiver misses a portion of the data stream due to an interference episode, it has to wait for the data to repeat again to achieve a complete ephemeris data download, significantly increasing TTFF. As Garmin noted in its initial comments, such

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below the data demodulation threshold, certified aviation receivers need to be able to continually decode navigation data (in particular, SBAS augmentation data) to meet integrity requirements and assure the continuity of service imperative for aviation safety. Section 2.1.1.2 of RTCA DO-229D (at 26) requires that "GPS satellite navigation data shall be continuously decoded." Section 2.1.1.5.5 of DO-229D (at 35) requires "designat[ing] any GPS satellite as ... UNHEALTHY" after [f]ailure of parity on 5 successive words (3 seconds)." Further, for SBAS satellites, Section 2.1.1.3.2 of DO-229D (at 27) requires the SBAS message loss rate to be less than 0.1% and section 2.1.1.4.9 of DO-229D (at 30) requires that, after four seconds of invalid data, the receiver will time out the SBAS integrity data, resulting in a loss of precision approach capability.

[14] Bullock, J. Blake, Michael Foss, G. Jeffrey Geier, and Michael King, "Integration of GPS with Other Sensors and Network Assistance," (in *Understanding GPS, Principles and Practice, 2nd Ed.*, Elliott Kaplan and Chris Hegarty, Eds. (Boston, MA: Artech House, 2006), at 509.

[15] Sturza Report at 8-9.

delays in acquisition can pose significant aviation risks, particularly in airplane approaches at airfields.[16]

Finally, the Sturza Report strongly supports Garmin's position that a 1 dB change in C/N_0 is a critical factor in assessing receiver performance due to the dependence of GPS receiver tracking loop error on C/N_0.[17] The Sturza Report notes correctly that code tracking loop error is the major contributor to measurement errors made by some GPS devices.[18] Further, Sturza clearly shows that the code tracking error varies as a function of C/N_0 – C/A code tracking error increases as C/N_0 decreases.[19] In fact, as Sturza's data clearly show, in dynamic applications with wider tracking loop bandwidths, small changes in C/N_0 yield substantial changes in C/A code tracking error, especially as C/N_0 approaches the acquisition sensitivity threshold.[20]

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[16] Garmin Comments at 11.

[17] *See* Garmin Comments at 15 & n. 36.

[18] Sturza Report at 10.

[19] Sturza Report at 12, Figure 6. 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 C/N_0 degrades, 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 addition, some GNSS applications also track the carrier phase of the signal from selected satellites in order to achieve sub-centimeter accuracy. "A 1 dB reduction in C/N_0 will also cause a tenfold decrease in the mean time between cycle slips in a GNSS receiver tracking loop." Garmin Comments at 15. A cycle slip represents an interruption in the phase tracking, which forces the carrier tracking loop to reacquire and reinitiate its measurements – lack of continuous carrier phase measurements renders many high precision applications unavailable.

[20] *See* Sturza Report at 12. Moreover, Sturza's proposed technique for overcoming this issue – moding – is not applicable to many receivers and is, therefore, unpersuasive. Moding is a technique in which a receiver dynamically adjusts its tracking loop parameters (longer integration times, tighter loop bandwidth, and narrower correlator spacing) in order to make the tracking loop error less dependent on C/N_0. *See* Sturza Report, Figure 7, at 13. Garmin notes that such dynamic adjustments to receiver parameters are not appropriate for all receiver types. *(...cont'd)*

Furthermore, Garmin notes that GPS receivers are designed to operate in a variety of conditions and at a variety of signal levels – some are even designed to operate in areas of lower signal strength where a 1 dB reduction in C/N_0 would cause an even more significant increase in the code measurement error and severely impact accuracy.[21] Therefore, Sturza data that show a 1 dB decrease in C/N_0 causing a five- to ten-meter increase in the C/A code tracking error standard deviation represent an unacceptable compromise of the accuracy of the receiver.[22] In other words, the Sturza Report's data confirm the necessity of the 1 dB standard as the only metric that effectively preserves all aspects of GPS receiver performance.[23]

The foregoing considerations strongly support the adoption of a 1 dB standard by illustrating the difficulty in creating representative use cases and scenarios to assess KPIs and further reinforce the value of a universal metric – 1 dB reduction in C/N_0 – for assessing interference.

The Sturza Report concurs and notes that lower tracking loop bandwidths are not appropriate for higher dynamic applications. *See* Sturza Report at 12.

[21] For example, many receivers are designed to operate in urban canyons, indoors for prisoner tracking applications, and under the forest canopy during search and rescue operations.

[22] *See* Sturza Report at 12, Figure 6.

[23] The Sturza Report attempts to avoid this conclusion by combining the C/A code tracking error with two other error contributions – "SIS" or signal-in-space errors and local error effects – and by assuming un-augmented GPS. *See* Sturza Report Figures 8 and 9, at 14-15. This ignores, however, the widespread use of differential corrections (such as WAAS, LAAS, and CORS) to reduce or eliminate the SIS errors, at which point the code tracking error has a greater contribution, and reductions in C/N_0 are a primary concern.

III. ASSURANCE OF AVIATION SAFETY REQUIRES IN-DEPTH FAA PARTICIPATION IN CRAFTING THE SPECIFICS OF AVIATION-RELATED PARAMETERS AND CONDITIONS AS THEY RELATE TO CERTIFIED AVIATION DEVICES

As noted in its initial comments, Garmin finds it promising that Ligado is continuing to work with the FAA and RTCA, Inc. on solutions related to certified aviation devices.[24] A very brief and general FAA-related license condition may be inadequate, however, to address issues regarding certified aviation devices that remain under FAA discussion as well as new issues that may arise from interference to GPS devices caused by Ligado's use of its downlink spectrum (1526 to 1536 MHz) and over which Ligado and the FAA may subsequently reach an impasse. The FCC, in consultation with the FAA and RTCA, must anticipate these concerns and address them prior to a grant, so an effective and practical license condition may be crafted.

For instance, such pre-grant FAA, RTCA, and FCC review is needed to resolve the concerning problem of the compatibility of Ligado base station emissions with certified aviation devices. As the June 2011 Technical Working Group "Final Report" noted, analysis of aviation impact from previous proposals of Ligado's predecessor was performed based on a maximum base station EIRP of 32 dBW.[25] As far as Garmin can tell, this power level, which caused concerns in RTCA DO-327,[26] is the same level at which Ligado still plans to proceed.[27] Ligado suggests that lowering its downlink (or base station) power to 15 dBW might allow compatibility with helicopter operators and also claims that a power level of 26 dBW would be compatible with fixed wing operations, but provides no supporting analysis or reference for these particular

[24] Garmin Comments at 4.

[25] Technical Working Group, "Final Report," IB Dkt. No. 11-109, at 38, *available at* https://www.fcc.gov/ecfs/filing/6016826095/document/7021690471 (last checked June 20, 2016).

[26] DO-327 at 13.

[27] Comments of Ligado Networks LLC, IB Dkt. No. 11-109, filed May 23, 2016, at 29.

parameters.[28] Granting the Modification Application on the hope that subsequent RTCA and FAA review will solve all currently known problems regarding certified aviation devices and reveal no additional or new problems seems administratively backwards and contrary to public interest requirements.

The compatibility of Ligado's proposed operations with certified aviation devices on board helicopters raises particular concerns. Helicopters use the same TSO-certified aviation equipment as fixed wing airplanes. Given this fact and the significant concerns that do remain with respect to use of certified aviation equipment on board helicopters, it is unclear how Ligado will resolve concerns related to helicopters without FAA mandating a new regulation that all helicopters must install new TSO'd equipment, meaning potential replacement of existing TSO'd equipment that today provides adequate functionality and operational performance. Such an approach would raise great costs for replacement itself and also for the attendant costs of certifying it prior to its installation in a particular helicopter model – not to mention an operator's inability to use its helicopters while the equipment is being replaced.[29]

Garmin does not believe, contrary to Ligado's assertions, that it has misunderstood its proposals related to certified aviation devices or that it has misunderstood the latest clarifications related to those proposals. Rather, these clarifications highlight the significant issues related to certified aviation devices and the problems that they raise for aviation safety. A very general license condition, simply relying upon the FAA, RTCA, and Ligado to resolve certified aviation device issues at some point in the future, overlooks the highly complex steps involved in aviation industry implementation as well as the need for establishment of a cross-agency enforcement

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[28] Ligado Comments at 6-7.

[29] *See* FAA Order 8150.1C, at 4, paragraph 2-6.b provides as follows: "**A TSO Marking Made Under a TSOA or LODA *Does Not* Mean the:** ... (2) The installation of the article is approved."

mechanism. Language in any FAA-related condition, as supplemented by the text of an accompanying decision, needs to be explicitly clear, unambiguous, and capable of widespread implementation without risking interference to certified aviation devices and aviation safety.

IV. CONCLUSION

Garmin does not object to grant of the Modification Applications, including specified power limits and out-of-band emissions limits, consistent with its settlement with Ligado. Garmin respectfully requests that these reply comments be taken into account as the FCC reviews the Modification Applications.

Respectfully submitted,

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