Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Office of Engineering and Technology	)	ET Docket No. 16-191
Announces Technological Advisory Council	)	
(TAC) Noise Floor Technical Inquiry	)	
	)	

COMMENTS OF THE GPS INNOVATION ALLIANCE

The GPS Innovation Alliance ("GPSIA") submits these comments in response to the Office of Engineering and Technology's Public Notice seeking comment on behalf of the Technological Advisory Council ("TAC") on changes and trends to the radio spectrum noise floor.[1] The Global Positioning System ("GPS") and Global Navigation Satellite System ("GNSS"), as well as augmentations to the GNSS system, operate in frequency bands allocated to the Radionavigation Satellite Service ("RNSS"). Changes in the noise floor have a much more significant impact on GPS and GNSS than on other services. Consequently, GPSIA supports the TAC effort to study and quantify the rise in the noise floor and looks forward to assisting the TAC in understanding the unique aspects of GNSS services and their relationship to the noise floor in the RNSS bands. Below, GPSIA addresses some of the questions raised in the Public Notice.

The GPSIA was formed in February 2013 to protect, promote, and enhance use of GPS and GNSS technologies. Members and affiliates of the GPSIA are drawn from a wide variety of fields and businesses reliant on GPS, including manufacturing, aviation, agriculture,

[1] *Office of Engineering and Technology Announces Technological Advisory Council (TAC) Noise Floor Technical Inquiry*, Public Notice, ET Docket No. 16-191, DA 16-676 (rel. Jun. 15, 2016) (the "Public Notice").

construction, transportation, first responders, surveying, and mapping. The GPSIA also includes organizations representing consumers who depend on GPS for boating and other outdoor activities and in their automobiles, smart phones, and tablets.

Questions 1 and 2: Is There a Noise Problem, and Where Does the Problem Exist?

GNSS, as a navigation system, operates differently than radio communications systems and is thus more susceptible to changes in the noise floor than many other services. The primary measurement in GNSS is the precise timing of bit transitions in the navigation signal. Precise timing and positioning requires sub-nanosecond measurement of bit edges and effective multipath rejection. Both, in turn, require wide receiver bandwidth. 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.[2] Thus, even minor increases in the noise floor impede the ability of GNSS receivers to extract signals from the noise, thereby degrading performance.

GNSS systems must be able to deliver a signal that is accurate, has integrity, and is available and continuous in nature in order to meet the needs of existing and future users. Degradation of any one of these four performance parameters – accuracy, integrity, availability, and continuity – will diminish the usefulness of GNSS to significant numbers of users.[3]

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[2] *See* P. WARD, J. BETZ, AND C. HEGARTY, "Interference, Multipath, and Scintillation," in UNDERSTANDING GPS PRINCIPLES AND APPLICATIONS, at 247 (C. Hegarty and E. Kaplan, eds., Artech House 2d ed. 2006).

[3] *See, e.g.,* DEP'T OF DEFENSE, DEP'T OF HOMELAND SECURITY, AND DEP'T OF TRANSPORTATION, 2014 FEDERAL RADIONAVIGATION PLAN, at 1-14, *available at* http://www.navcen.uscg.gov/pdf/FederalRadionavigationPlan2014.pdf (last visited Aug. 11, 2016) ("Non-interference with PNT [position, navigation, timing] spectrum is crucial. All domestic and international PNT 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.").

Relatively small increases in the noise floor may affect any one of these four parameters in unexpected or dramatic ways, and each of the attributes can be degraded by varying amounts.

For example, a 1 dB increase in the noise floor within the RNSS band would cause a tenfold decrease in the mean time between cycle slips in a GNSS receiver tracking loop as shown in Figure 1 below. Most GNSS systems rely on continuous tracking of the signal carrier of each satellite being tracked in order 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 ascertained at sub-centimeter levels. A cycle slip interrupts this continuous carrier phase, forcing the tracking loop to reacquire the carrier, and then re-initiate the carrier phase measurement. Lack of continuous carrier phase renders many high precision applications unavailable.

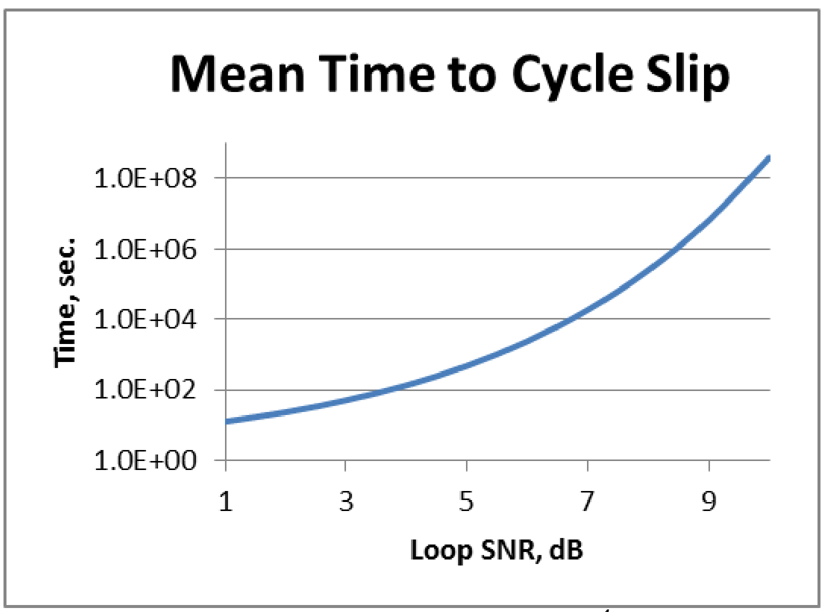

Figure 1: Mean Time to Cycle Slip[4]

[4] As shown in the chart in Figure 1, 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 the noise floor and receiver C/N_0). In other words, cycle slips occur 10 times more frequently when the noise floor is increased by

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

Degradation may also occur before the point at which there has been a 1 dB increase in the noise floor, or before the point at which the noise due to interference has increased by 25 percent.[5] 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,

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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 24 Formula 47 (IEEE Press 1986).

[5] Memorandum from National Space-Based PNT Executive Steering Group to Administrator, National Telecommunications and Information Administration ("NTIA"), June 14, 2011, at 4, *available at* https://www.ntia.doc.gov/files/ntia/publications/ligtsquared_assessment_report_07062011.pdf (last visited Aug. 11, 2016).

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 as spectrum use evolves.

For this reason, the International Telecommunications Union (the "ITU") has consistently applied an interference to noise ratio ("I/N") of -6 dB (equivalent to a 1 dB rise in the noise floor) in proceedings related to GNSS, other non-communications services, and some radiolocation services.[6] In other words, aggregate interference is limited to a 1 dB increase in the overall noise floor, and, in GNSS receivers, this is most readily observed as a 1 dB decrease in the carrier to noise power density ratio ("C/N_0").[7] The ubiquity of this "1 dB standard" in the ITU and other domestic and international proceedings reiterates the importance of characterizing and understanding the noise floor and validates the work TAC proposes to undertake.[8]

While overall increases in the noise floor due to the amalgamation of interference from numerous low-level sources is concerning, the TAC also asks for input on expected major sources of noise. GPSIA notes that mobile handsets require particular attention because of their

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[6] There are many examples of ITU Recommendations that utilize an I/N ratio of -6 dB, either directly or indirectly. For example, ITU-R M.1902-4 relies on this criterion to determine protection criteria for RNSS and ARNSS receivers. Similarly, ITU-R M.146x documents apply this same criterion to radar transceivers. In addition, some ITU Recommendations use even stricter criteria, in some cases I/N = -10 dB.

[7] It is critical that any interference to GNSS systems be evaluated using a consistent, objective and quantifiable metric – specifically, whether there is a 1 dB degradation to C/N_0. This metric is widely recognized and has been used by the GNSS industry, FCC, and NTIA for many years. For example, in its 2005 report on interference protection criteria ("IPC"), NTIA performed an exhaustive survey of both domestic and international IPC for various radio services and noted that "[o]ne common feature was that for continuous, long-term interfering signal levels, nearly all established IPC were based on an interference-to-noise power ratio of - 6 to - 10 dB." *See* NTIA Report 05-432, "Interference Protection Criteria," at ii, *available at* www.ntia.doc.gov/files/ntia/publications/ipc_phase_1_report.pdf (last visited Aug. 11, 2016).

[8] The I/N metric used in the ITU is band-agnostic and is applied variously throughout the radio spectrum; however, here GPSIA notes that it is specifically applied to the frequency bands allocated to the Radionavigation Satellite Service where GPS and GNSS operate (GPS L1: 1559-1610 MHz, GPS L2: 1215 – 1230 MHz, GPS L5: 1164 – 1215 MHz).

proliferation in recent years and the likelihood of their use in close proximity to GNSS receivers, particularly consumer-grade receivers often used in safety-of-life applications.

Question 3: Is There Quantitative Evidence of the Overall Increase in the Total Integrated Noise Floor Across Various Segments of the Radio Frequency Spectrum?

Based on available technical data, GPSIA believes that there is quantitative evidence of noise floor increases in key areas of the radio frequency spectrum. Technical studies conducted in 2004 and 2008 measured and quantified the noise level in the GPS L1 band in a variety of locations and environments. The 2004 study found that the GPS L1 band was then "relatively pristine" compared to two other observed bands, at 2.0 GHz and 2.4GHz.[9] The 2008 study, however, notes that the noise floor is increasing and concluded that "there is a serious risk that the aggregate signals from multiple devices may cause severe interference in safety-critical applications such as aviation."[10] The 2008 study considered cell phone spurious emissions, man-made background noise, and ultra-wideband devices as contributors to increased noise floor levels. As a result, the FCC established a frequency mask to protect the range of frequencies where RNSS bands reside, 1-3 GHz. These two prior studies and the methods employed can form the basis for future noise studies of the RNSS bands, as well as helping to document noise level changes over time.

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[9] J. DO, D. AKOS, AND P. ENGE, "L and S Bands Spectrum Survey in the San Francisco Bay Area," in IEEE Position Location and Navigation Symposium, 2004, April 26-29, 2004, at Section IV, *available at* http://gps.stanford.edu/papers/Do_IEEEIONPLANS_2004.pdf (last visited Aug. 11, 2016) ("IEEE Paper"). The IEEE Paper is based on a NASA-sponsored study conducted by Stanford University. *See* P. ENGE, J. SIMONEAU, L. PEARSON, AND V. SEETHARAM, "Measurements of Man-Made Spectrum Noise Floor," NASA CR-2004-213551, *available at* http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050041714.pdf (last visited Aug. 11, 2016) ("NASA CR-2004-213551").

[10] B. BRODSKY, J. HOLLANSWORTH, J. MILLER, AND A. ORIA, "NASA RNSS Spectrum Protection Activities," in Proceedings of ION GNSS 2008, September 16 - 19, 2008, at 9, *available at* https://www.ion.org/publications/pdf.cfm?articleID=8146 (last visited Aug. 11, 2016) (subscription required; copy available upon request).

Question 4: How Should a Noise Study Be Performed?

GPSIA offers three specific comments in response to TAC's questions regarding how a noise study should be conducted – a study that is of utmost importance to the public interest. First, because of the study's importance, GPSIA recommends that it be conducted as a government activity, at government expense, and not delegated to private parties or quasi-governmental resources that may rely on private funds to conduct the study.

As noted above, while increases in the noise floor affect a wide variety of non-communications devices (*e.g.*, radars), GNSS services, in particular, are especially vulnerable to increases. GNSS devices are also utilized in a wide variety of applications. As a second point, GPSIA urges that any testing must account for that diversity and be cognizant of GNSS' unique vulnerability. For instance, GNSS receivers are a key component in safety-of-life systems for fixed and rotary-wing aircraft as well as in unmanned aerial vehicles; noise measurements must be undertaken at various altitudes relevant to such systems.

Third, TAC should work to ensure that the measurement levels and bandwidths in any study are useful to GNSS systems. For example, crowdsourcing such a study by using mobile devices may be a tempting option in order to collect a great deal of data quickly; however, such devices lack the sensitivity needed to make accurate measurements of the noise floor in GNSS bands. As noted, GPS receivers operate below the noise floor; while GPSIA fully recognizes the difficulty in measuring noise contributions at or around the noise floor, such measurements are critical in and around bands used for navigation. In that regard, GPSIA encourages TAC to consider the noise floor measurement guidance provided by NASA in response to previous inquiries.[11] Further, GPSIA encourages TAC to utilize the methods and metrics employed by

[11] NASA CR-2004-213551 at Sections 2.2-2.4.

NASA in order to ensure historical consistency in observing the GNSS noise floor and any changes that may occur.

As demonstrated above, both the FCC and the ITU have historically maintained a quiet radio frequency spectrum neighborhood for GNSS receivers, along with other technologies that utilize faint radio signals and sensitive receivers – a spectrum neighborhood populated by similar users. As noted in the IEEE Paper, "[t]aken together, the measurement data in this study send a message – regulation must be very sensitive to the function of the band, because the rules determine the radio environment. Open bands, like the ISM band, do become populated with the man-made signals. This openness brings many terrestrial users and great utility, but does render the band useless for space-base-based applications. . . . The GPS band serves safety-critical applications everywhere. Hence, a most restrictive regime is needed here and the natural noise floor should be the basis of the operation in this band."[12]

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GPSIA looks forward to continuing to cooperate with the TAC and the FCC as they continue to consider this important issue.

Respectfully submitted,

/s/
Scott Burgett

GPS Innovation Alliance
2000 K Street, NW
Suite 600
Washington, DC 20006
(202) 416-6282

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12 IEEE Paper at Section V.