Before the
DEPARTMENT OF DEFENSE
Fort Meade, MD 20755-0549

Next-Generation Electromagnetic Spectrum Strategic Roadmap	))))	Notice ID 632369514

COMMENTS OF THE GPS INNOVATION ALLIANCE

The GPS Innovation Alliance ("GPSIA") respectfully submits these comments in response to the Department of Defense's ("DoD's") Request for Information to guide the development of a Next-Generation Electromagnetic Spectrum ("EMS") Strategic Roadmap ("Roadmap").[1] GPSIA supports DoD's efforts to develop this Roadmap and applauds DoD's recognition that spectrum is a scarce resource that must be used efficiently. A necessary element of the Roadmap must be providing current and future DoD users with sufficient regulatory protection from interference for the spectrum and services upon which they rely. In particular, the Roadmap should acknowledge that the critical services provided to DoD and others by Global Navigation Satellite Systems ("GNSS") like the U.S. Global Positioning System ("GPS") must continue to operate in a spectrum environment free from harmful interference. It should also recognize that, because of the unique characteristics of GPS as a navigation system, a "zoning" approach to spectrum management and continued endorsement of the 1 dB interference-avoidance standard are important tools to accomplish that shared goal.

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[1] *Next-Generation Electromagnetic Spectrum Strategic Roadmap*, Notice ID 632369514, Request for Information (rel. Jan. 4, 2023) ("*RFI*").

I. INTRODUCTION

Over the last several decades, GPS-enabled technology has become a critical part of our national infrastructure, ingraining itself more deeply every year. In addition to use in warfighting systems and across warfighting domains, GPS and its applications create widespread economic benefits across an incredibly broad cross-section of industries, ranging from manufacturing, surveying, mapping, and agriculture to construction, transportation, aviation, and emergency response. GPS-based technologies also touch the lives of millions of consumers every single day, including those who depend on GPS for boating and other outdoor activities, and in their automobiles, farm vehicles, smart phones, and tablets. GPS is a highly innovative, successful, and ubiquitous technology that has injected almost $1.7 trillion into the nation's economy[2] and is critical to the smart infrastructure, services, and applications of today, tomorrow, and decades to come.

The satellites that transmit GPS signals are owned by the United States and operated by the U.S. Space Force, making DoD's role in maintaining GPS's fundamental relationship to the nation's economy, infrastructure, and national security critically important. And because GPS and GNSS play an irreplaceable role in the daily activities of individuals and businesses worldwide, including for safety-of-life services, DoD must ensure that these systems are protected from harmful interference in a manner that is universal, predictable, and

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[2] *See* RTI International, *Economic Benefits of the Global Positioning System (GPS)*, at ES-1 (June 2019) ("RTI Study"), https://www.rti.org/sites/default/files/gps_finalreport.pdf (citing $1.4 trillion in 2017, which was converted to 2022 dollars using the U.S. Bureau of Labor Statics' CPI Inflation Calculator); Michael P. Gallaher, *Economic Benefits of the Global Positioning System (GPS), Presentation at the Positioning, Navigation and Timing Advisory Board Meeting* (Nov. 20, 2019), https://www.gps.gov/governance/advisory/meetings/2019-11/gallaher.pdf.

quantifiable. GPSIA looks forward to assisting DoD in the development of the Roadmap in a manner that reflects the importance of GPS to DoD's EMS superiority and to supporting its continued efforts to protect, preserve, and promote GPS.

II. DOD'S ROADMAP SHOULD ACKNOWLEDGE THE UNIQUE CHARACTERISTICS OF GPS AND THE NEED TO PROTECT MISSION-CRITICAL SERVICES.

As a navigation system, GPS operates fundamentally differently than radio communication systems, with inherently different technical and functional attributes. While communication systems decode data bits, navigation systems measure the precise timing of bit transitions in order to derive precise timing and positioning information. These sub-nanosecond measurements of bit edges require wide receiver bandwidth, which also aids in effective multipath rejection.

GPS satellites orbit more than 12,000 miles above the Earth and rely on solar panels to generate the power needed to transmit GPS signals. Those signals are received by GPS devices on the ground at power levels of less than a millionth of a billionth of a watt.[3] To put it another way, when coupled with the fact that GPS signals are spread spectrum, the low transmit power level at which GPS signals are transmitted and the distance which they must travel result in signals that are well below the thermal noise floor when they are received on Earth. This requires GPS receivers to perform the extraordinary engineering feat of extracting these faint

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[3] *See*, *e.g.*, Tim Bartlett, *Threats to GPS from Land-Based Signal Boosters*, POWER AND MOTORYACHT, May 7, 2012, https://www.powerandmotoryacht.com/electronics/understanding-impactthreats-gps-land-based-signal-boosters ("GPS signals come from solar-powered 50-Watt transmitters 12,000 miles out in space."); *see also* Sebastian Anthony, *Think GPS is Cool? IPS Will Blow Your Mind*, EXTREMETECH, Apr., 24, 2012, http://www.extremetech.com/extreme/126843-think-gps-is-cool-ips-willblow-your-mind ("Detecting a GPS signal on Earth is comparable to detecting the light from a 25-watt bulb from 10,000 miles.").

signals from the noise, processing them, and delivering precise positioning, navigation, and timing information to end users.

For GPS and GNSS systems to meet the needs of existing and future users, it is essential that they continue to be able to deliver and receive signals that are accurate, have integrity, and are available and continuous in nature. The accuracy,[4] integrity,[5] availability,[6] and continuity[7] requirements of space-based navigation systems like GPS enable high-risk, high-consequence safety-of-life services that can be mission-critical to the warfighter. Such systems differ greatly from consumer-grade terrestrial high-power communication systems operating above the noise floor. Indeed, even minor increases in the effective noise floor can impede the ability of GPS receivers to extract navigation and timing signals from the noise, thereby

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[4] 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. 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.

[5] 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. Like accuracy, integrity alone is insufficient to ensure functioning of GNSS.

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

[7] 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.

degrading performance. Although the brief loss of connectivity in a communication system may be inconsequential during a non-emergency situation, losing the mission-critical, safety-of-life services that rely on GPS – even momentarily – would prove catastrophic.

Accordingly, the Roadmap must consider that systems that support *navigation* functions are sensitive to interference in different ways than systems that operate *communications* services. And because DoD's continued EMS superiority necessarily depends on the ability of spectrum-based navigation systems like GPS to operate in an interference-free environment, DoD should seek to protect GPS from both in-band *and* adjacent-band interference, particularly when services in adjacent spectrum bands operate at higher power levels.

III. A "Spectrum Zoning" Approach Can Be Effective in Providing Interference Protection.

As the RFI recognizes, DoD's laudable focus on identifying innovative and advanced forms of potential spectrum sharing tools and opportunities must be balanced against the need to provide current and future DoD users with sufficient regulatory protection.[8] It adds that spectrum sharing should not result in degradation, harmful interference, or the loss of access to spectrum to or amongst incumbent users.

GPSIA supports spectrum sharing under these conditions and urges DoD to consider the use of a "zoning" approach when evaluating opportunities for spectrum sharing, particularly if a newly introduced service has the potential to cause interference to GPS. A zoning approach would group similar spectrum-based services together, to the greatest extent possible, to minimize the number of band edges or "border areas" where dissimilar uses in close proximity create serious interference challenges. Not only would this approach take into account the

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[8] *See RFI* at 3.

distinctions highlighted above between communication and navigation systems, but it would also create efficiencies and a stable and quiet radio environment that would protect the vital services provided by DoD and other incumbent users.

A zoning approach ensures regulatory predictability, facilitating the development of new spectrally efficient capabilities and techniques and helping to guarantee compatibility among different services. While the technology embedded in GPS-reliant devices is constantly being updated, as the RFI notes, such capabilities and techniques often "require long acquisition lead times and must be supported by millions if not billions of dollars to perform the underlying research, development, test, and evaluation and then integration into military operations."[9] Moreover, the development of those capabilities assumes that sharing is even technically feasible. As the Ligado proceeding before the Federal Communications Commission ("FCC") has demonstrated, while some techniques to promote sharing and mitigate interference may suit communication systems, they may have a deleterious effects on navigation systems.[10] A zoning approach that minimizes the number of dissimilar spectrum allocations in close spectral proximity to each other would avoid instances of incompatible use in the first place, while still allowing spectrum to be shared or reallocated for terrestrial use. Indeed, had the FCC used a zoning approach and maintained the well-established "quiet neighborhood" for GPS operations in the Ligado proceeding, it would have avoided the years' long conflict and regulatory instability it created.

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[9] *RFI* at 2.

[10] *See* National Academies of Sciences, Engineering, and Medicine, *Analysis of Potential Interference Issues Related to FCC Order 20-48* (2022), https://doi.org/10.17226/26611 ("NAS Report").

IV. The 1 dB Metric Is the Most Comprehensive and Informative Choice for Evaluating Harmful Interference.

In addition to a zoning approach, DoD's spectrum management decisions should embrace the 1 dB metric as the appropriate interference protection criterion to determine spectrum compatibility between GNSS systems like GPS and other services. This metric, which measures whether a new service causes a 1 dB degradation in a receiver's reported Carrier-to-Noise Power Density Ratio (C/N_0), corresponds to a 25-percent increase in the noise floor, and is associated with quantifiable changes in the overall noise to which GNSS receivers are subject. It is based upon well-understood GNSS engineering considerations, with equally well-understood effects on receiver operation.

In fact, the 1 dB metric provides a universal ability to assess receiver performance while also quantifying the effects of interference on GNSS receivers from both in-band and out-of-band emissions. Out-of-band emissions create a phenomenon known as "overload" interference. Overload interference occurs when extremely powerful transmissions in nearby bands overwhelm the front-end filtering in the GNSS receiver, saturating the receiver electronics and degrading its performance. As noted above, GPS receivers are designed to receive faint GPS signals transmitted from thousands of miles away and therefore must be protected from high power terrestrial transmissions both in *and* outside the frequency band in which the receiver is designed to operate.

Use of the 1 dB interference standard is particularly necessary to accommodate the technical characteristics of navigation receivers and ensure the accuracy, integrity, continuity, and availability of GNSS signals. For example, most GNSS systems rely on continuous tracking of the signal carrier of each satellite being tracked in order to maintain maximum accuracy and integrity. 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 1 dB decrease in C/N_0 within the spectrum band, however, causes a tenfold decrease in the mean time between cycle slips in a GNSS receiver tracking loop. Cycle slips, in turn, interrupt the continuous carrier phase, forcing the tracking loop to reacquire the carrier and then re-initiate the carrier phase measurement. In other words, the measurement cycle is interrupted and must be restarted. This lack of continuous carrier phase renders many high precision applications unavailable.

Similarly, 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, which 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 determine the distance to the satellite. However, as the noise floor rises, the increased noise makes it more difficult to precisely synchronize the replica PRN code to the broadcast signal, introducing error into the measurement of distance to the satellite. Such errors begin to accrue in noticeable ways before the point at which there has been a full 1 dB reduction in C/N_0; therefore, it is critical that interference levels not be permitted to exceed the 1 dB metric.

Recent analyses conducted by the National Academies of Sciences, Engineering, and

Medicine ("NASEM"),[11] as directed by Congress,[12] confirm that an approach to interference analysis based on C/N_0, (which NASEM more generally referred to as signal-to-noise ("SNR") ratio), is the appropriate mechanism for evaluating harmful interference to GPS receivers.[13] NASEM recognized that the 1 dB metric would provide a conservative result that "precludes harmful interference in virtually all use cases."[14] It also found that a C/N_0-based approach is more predictive of receiver performance and, therefore, can help identify harmful interference across a broad set of use cases.[15] NASEM noted that it "would have chosen SNR degradation as the clear favorite for deciding whether or not Harmful Interference had occurred" in the Ligado proceeding under certain circumstances.[16]

As the GPS industry has repeatedly explained, the 1 dB metric has for years been relied upon internationally by the GNSS industry and by regulators around the world when designing, operating, and evaluating GPS receivers. Given the very long useful life of GPS receivers as well as the fact that GPS-enabled equipment can be highly integrated in devices used by DoD and other Federal agencies for mission-critical services, GPSIA urges DoD to make sure that the

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[11] *Id.*

[12] *See* William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116-283, 134 Stat. 3388, 4074 § 1663.

[13] *See* NAS Report at 2, 37 (finding that the use of an SNR ratio would be a more "comprehensive and informative" approach to evaluating harmful interference to GPS devices than the approach used by the FCC in the Ligado proceeding).

[14] NAS Report at 37.

[15] *See* NAS Report at 2-3, 42.

[16] NAS Report at 42 (suggesting the SNR approach would have been preferred if the question the Committee was tasked to answer was "posed in a way that allowed for the nuances of the SNR approach . . . with some recognition of the applicability of receiver standards").

Roadmap acknowledges that the 1 dB metric remains the most appropriate tool for assessing harmful interference to GNSS services like GPS.

V. CONCLUSION

GPSIA appreciates DoD's effort to develop the Roadmap. As part of that effort, DoD should recognize the critical difference between communication and navigation systems and support the maintenance of a spectrum environment that groups like services together. It also should continue to endorse the 1 dB metric for evaluation of harmful interference to navigation services. These spectrum management tools have maximized spectrum efficiency and allowed GPS, in particular, to become the world-leading and ubiquitous navigation technology that it is today.

Sincerely,

/s/ Alex Damato

Alex Damato
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