Assessment of LightSquared Terrestrial Broadband System Effects on GPS Receivers and GPS-dependent Applications

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Executive Summary

The Executive Steering Group (ESG) of the National Executive Committee (EXCOM) for Space-Based Positioning, Navigation, and Timing (PNT) directed the National Space-Based PNT Systems Engineering Forum (NPEF) to conduct an assessment of the effects of LightSquared's planned deployment of a terrestrial broadband network to Global Positioning System (GPS) receivers and GPS-dependent systems and networks. The NPEF was tasked to engage with the LightSquared Working Group established at the direction of the Federal Communications Commission (FCC), and the GPS manufacturing and applications communities through relevant industry bodies (e.g., the U.S. GPS Industry Council and RTCA, Inc.). The NPEF investigated and determined effects due to interference from LightSquared Ancillary Terrestrial Component (ATC) transmitters operating in the 1525-1559 MHz frequency band to a selected set of GPS receivers based on operationally relevant scenarios. While the NPEF tasks were conducted in coordination with all involved entities to the extent possible, the NPEF report is considered to be an independent assessment. The contents of this Report consist of a compilation of findings from nine subtasks along with appendices that include summaries of all of the detailed test data and results collected over the last four months via a series of laboratory and field environment testing of GPS receivers. This Report is a summary of the work conducted during this effort and includes specific recommendations and responses to questions as requested by the EXCOM.

Based on analysis described in the main body of this Report, the NPEF has developed the following recommendations for ESG consideration.

<u>Recommendation 1</u>: *Move to rescind the FCC conditional waiver (FCC Order DA 11-133) of January 26, 2011 authorizing terrestrial only ATC operation in the Mobile Satellite Service (MSS) 1525 - 1559 MHz Band.*

Test results of the LightSquared Phase 0, Phase 1, and Phase 2 deployments of ATC transmitters utilizing the MSS band (1550.2 – 1555.2 MHz for Phase 0, 1526.3 – 1531.3/1550.2-1555.2 MHz for Phase 1, and 1526-1536/1545.2 – 1555.2 MHz for Phase 2) have demonstrated there are significant detrimental impacts to all GPS applications assessed as part of this NPEF effort. These impacts encompassed both US Government and commercial GPS applications. The potential degradation of GPS operation due to LightSquared emissions was further characterized via simulation that showed that completion of the network of high-powered base stations envisioned by LightSquared would result in degradation or loss of GPS function (ranging, position) at standoff distances of a few kilometers extending to space operations. Possible mitigations for GPS applications were identified and evaluated but were deemed impractical as they would require significant modification or complete redesign and replacement of currently fielded GPS equipment. The timeline to field new GPS receivers for some applications, from initial concept development through production, can take 10-15 years. Finally, there remain certain applications that even with modification or complete redesign would still not be able to perform their current mission in the presence of such Network broadcasting directly adjacent to the GPS L1 band.

Recommendation 2: *The U.S. Government should conduct more thorough studies on the operational, economic and safety impacts of operating the LightSquared Network, to include additional ATC signal configurations not currently in LightSquared planned spectrum phases, effects on timing receivers, as well as transmissions from LightSquared handsets.*

Initial test results demonstrated that some applications (e.g. aviation) were able to operate with little to no degradation when only a 5 or 10 MHz channel (1526.3 – 1531.3 MHz or 1526 – 1536 MHz) in the lower portion of the MSS spectrum was utilized for the LightSquared broadcast. However, for other applications, GPS loss of function still occurs at unacceptable distances to LightSquared towers. Use of only the lower portion of the L-band MSS spectrum is *not* one of the planned Phases for the LightSquared Network evolution so only limited testing has been conducted under this scenario. Additionally, no tests on LightSquared handset (or user terminal) transmissions were conducted as part of this NPEF study, due to non-availability of hardware. LightSquared handsets will transmit in the band 1620.5-1660.5 MHz and the potential for interference to GPS receivers given the very close proximity to an arbitrary number of LightSquared users remains to be evaluated. Evaluation of the LightSquared emissions effects on timing receivers was not thoroughly addressed during the course of this NPEF investigation. An additional evaluation period of at least six months would enable completion of a thorough assessment of the LightSquared Network and should be conducted to allow the EXCOM to make informed decisions on impacts, mitigations, and the way forward for all GPS users. Note, however, it is not clear that LightSquared can provide its planned 4G LTE services levels using only the lower 5 MHz or even 10 MHz channel location.

Recommendation 3: *Based on testing of representative ATC equipment which became available for the first time during this NPEF evaluation, we strongly recommend the FCC revisit and readdress the effects of the 2003-2010 ATC authorizations within the MSS L-Band spectrum on GPS applications.*

At the conclusion of this NPEF effort significant concerns remain that operation of an ATC integrated service as originally envisioned by the FCC *cannot* successfully coexist with GPS. Until the FCC granted a conditional waiver to LightSquared in January 2011, operation of terrestrial services under the MSS ATC regime had been coupled with the MSS satellite service so that the MSS L-band remained primarily a limited power space service downlink band that ensured compatibility with adjacent band space services such as GPS. Rigorous analysis of systems compatibility had also been impossible prior to now due to non-availability of relevant commercial ATC equipment. As with recommendation #2, this recommendation suggests there's need for additional assessment of previous rulemaking to determine if authorized ATC architectures in the MSS L-band could be tolerated by GPS applications in any form.

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Background

U.S. Space-Based Positioning, Navigation, and Timing Policy states that a "fundamental goal of this policy is to ensure that the United States maintains space-based positioning, navigation, and timing services, augmentation, back-up, and service denial capabilities that: (1) provide uninterrupted availability of positioning, navigation, and timing services; (2) meet growing national, homeland, economic security, and civil requirements, and scientific and commercial demands; (3) remain the pre-eminent military space-based positioning, navigation, and timing services; (4) continue to provide civil services that exceed or are competitive with foreign civil space-based positioning, navigation, and timing services."

GPS modernization includes new signals and capabilities required to be compatible with the use of existing GPS receivers designed in compliance with specifications and standards in existence at the time of the receiver design. Compatibility with federal augmentation system (Wide Area Augmentation System [WAAS], Local Area Augmentation System [LAAS], Nationwide Differential GPS [NDGPS], and Maritime DGPS [MDGPS]) receivers in accordance with the specifications of these systems is also required.

Further, in 2004, the U.S. signed an agreement with the European Union establishing cooperation between GPS and the European Galileo system. The Agreement specifically states "The Parties shall work together to promote adequate frequency allocations for satellite-based navigation and timing signals, to ensure radio frequency compatibility in spectrum use between each other's signals, to make all practicable efforts to protect each other's signals from interference by the radio frequency emissions of other systems, and to promote harmonized use of spectrum on a global basis, notably at the ITU."

In 2007, the U.S. Federal Aviation Administration (FAA) submitted a letter to the International Civil Aviation Organization (ICAO), in lieu of an agreement, which "reaffirms the United States Government's commitment to provide the Global Positioning System (GPS) Standard Positioning Service (SPS) for aviation throughout the world. Further, the United States commits to provide the Wide-Area Augmentation System (WAAS) service within its prescribed service volume." The letter goes on to state that "The U.S. Government plans to take all necessary measures for the foreseeable future to maintain the integrity, reliability and availability of the GPS SPS and WAAS service and expects to provide at least six years' notice prior to any termination of such operations or elimination of such services."

On 9 Feb 2011, the Executive Steering Group (ESG), via the National Coordination Office (NCO) of the National Executive Committee (EXCOM) for Space-Based Positioning, Navigation, and Timing (PNT), directed the National Space-Based PNT Systems Engineering Forum (NPEF) to conduct an assessment of the effects of LightSquared's planned deployment of terrestrial broadband systems to GPS receivers and GPS-dependent systems and networks (see Appendix A).

This Report is a summary of the work conducted on this Task (see Appendix B) and includes specific Recommendations as requested by the EXCOM. Department of Defense (DoD) findings for the Task are captured separately given their security classification.

Summary of Task Findings

The following material is a summary of the various subtasks performed in response to the EXCOM NPEF request. Detailed reports for each of the subtasks performed by the NPEF are included in Appendix B and contain additional data and information.

Task 1: Signal Specifications & Characteristics

The relevant technical information on LightSquared specifications and GPS applications were investigated and documented. Details of the LightSquared signal include intended LightSquared channel configurations, antenna characteristics, out of band emissions, tower density and handset technical parameters. Figure 1 depicts the LightSquared plans for three spectrum deployment phases (though the L1 identified in this Figure represents only the main lobe of the C/A portion of the GPS L1 signals) .

- Phase 0: One 5 MHz channel: 1550.2 MHz- 1555.2 MHz, 62 dBm effective isotropic radiated power (EIRP) per 5 MHz channel, per base station sector.
- Phase 1: Two 5 MHz channels: 1526.3 MHz -1531.3 MHz & 1550.2 MHz - 1555.2 MHz, 62 dBm EIRP per 5 MHz channel, per sector.

  Phase 2: Two 10 MHz channels: 1526 MHz -1536 MHz & 1545.2 MHz - 1555.2 MHz, 62 dBm EIRP per 10 MHz channel, per sector.

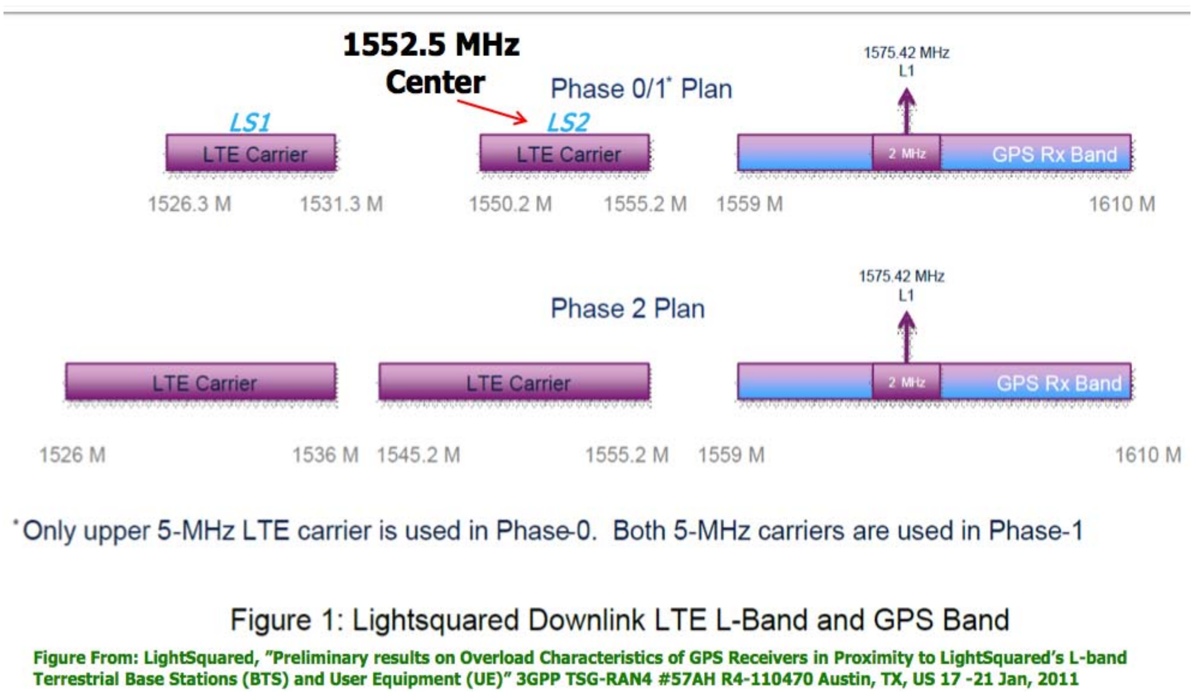

Figure 1. LightSquared Signal Spectral Occupancy

LightSquared will utilize the prevalent fourth-generation cellular standard, known as Long Term Evolution (LTE), for their terrestrial network and has stated their intention to always operate ATCs at least 4 MHz separated from the start of the GPS L1 band (1559 MHz). It should be noted however, there is *no* regulatory requirement to maintain this guardband nor does LightSquared's MSS ATC authorization impose such a restriction. In addition, the FCC authorization permits use of ATC power levels as much as 10 dB in excess of what LightSquared intends to use and, as a consequence, tests could not be conducted at the maximum allowable ATC levels. At these allowable higher levels there may be additional deleterious effects, such as intermodulation products caused by ATC emissions that are as yet unobserved but can be confirmed with additional testing.

GPS application requirements obtained for this evaluation vary greatly in specificity, with very detailed requirements identified for aviation to much less information for other classes of GPS users. GPS application requirements were obtained primarily from the Technical Working Group (TWG) which reports to the LightSquared Working Group established at the direction of the Federal Communications Commission (FCC). The TWG categorized GPS applications under the following classes: aviation, cellular, general position/navigation, high precision, networks, and space. Key requirements for these categories of applications are contained in the Task 1 detailed report in Appendix B.

Task 2: Model Characterization of the Terrestrial Broadband Network

The ATC locations of sites planned for the initial deployment by LightSquared were provided to the NPEF. The separation distance between these base stations depends on type of morphology around each site as well as capacity and coverage considerations. The maximum number of LightSquared Network handsets a single ATC tower can support depends on the demand and service profile of each mobile device / handset. A typical site with the Phase 2 construct using two 10 MHz channels can support 1200 users in active state and a much higher number in dormant state. For the LightSquared Network deployment of base stations by 2015, LightSquared expects that the distance between base stations would typically be:

- Dense urban environment: 0.4-0.8 km
- Urban environment: 1-2 km
- Suburban environment: 2-4 km
- Rural environment: 5-8 km

Tower locations provided by LightSquared for their initial deployments were used in Task 6 as part of the aviation and space simulation scenarios.

Task 3: RF Interference in Operational Scenarios

The NPEF utilized the operational scenarios developed in the TWG and RTCA forums. TWG scenarios were developed for each of the receiver categories mentioned in Task 1. The scenarios considered most relevant to the NPEF test effort were those for aviation, space, and scientific applications. The aviation scenarios covered en Route, terminal and approach, and surface operations. The spaceborne scenario investigated radio occultation (RO) applications where the

GPS receiver antenna is directed towards the Earth limb in order to measure properties of the atmosphere and typical navigation applications.

Task 4: Receiver Performance Metrics

The NPEF documented several metrics useful to assess performance of a GPS receiver under interference conditions. These metrics include carrier to noise density ratio (C/N_0), pseudorange and carrier phase measurement quality, carrier phase measurement continuity, automatic gain control characteristics, and position/time quality. Additionally some applications measured the ability to acquire or reacquire the GPS L1 signal. While all these metrics have utility in evaluating performance effects, due to the time constraint for this effort receiver characterization under LightSquared interference conditions concentrated on C/N_0 and loss of position/time quality. Loss of position/time quality was referred to as loss of satellite tracking. For NASA, loss of tracking meant no data, rather than poorer quality data, was produced by the unit under test.

Task 5: Expected and Potential Effects on GPS Users

GPS susceptibility tests were conducted using various LightSquared signals and test environments. Conducted emissions testing was accomplished in laboratory environments, radiated emissions testing was performed in an anechoic chamber, and 'nominal' operations testing utilized the 'live sky' environments provided by the current GPS constellation. Test results were obtained from several different types of receivers with applications ranging from aviation to survey to space.

Tables 1 and 2 provide summaries of the standoff distances where civil receivers indicated a 1 dB degradation in C/N_0 and when satellite tracking was disrupted (loss of lock) in the presence of LightSquared emissions. The 1 dB degradation point (approximately 25% loss in effective signal power) is not necessarily a tolerable level of degradation from LightSquared emissions but is useful to highlight the onset of severity associated with these emissions. For example, some tested aviation receivers could not meet their WAAS word error rate requirements in the presence of LightSquared interference that caused a 1 dB degradation in C/No. These results are for a single LightSquared base station and do not address aggregate power from multiple base station scenarios (see Task 6 for specific applications). In lieu of listing specific receiver results, the Tables categorize receivers into functional areas and then provide ranges to cover the degradation observed for these receivers against each specific LightSquared signal type. (Note that the separation distances in these Tables are used to compare the relative sensitivity of different classes of receivers and are based on free space propagation path loss where the receiver is in the main beam of the LightSquared base station transmission.) In addition to the LightSquared-proposed spectrum deployment phases, results for a single 10 MHz Low channel are also provided in these Tables since there was initial exploratory evaluation of a modified LightSquared spectrum deployment that might prove viable as a mitigation approach for some GPS applications.

Results in these Tables demonstrate that for *all* GPS applications assessed during this NPEF effort, the LightSquared signal caused degradation at distances of approximately one kilometer to several hundred kilometers for LightSquared Phase 0, 1 and 2 configurations. These distances are in excess of the planned spacing between base stations for all but the most rural areas. Further, as shown in the Task 6 assessments, there is also an aggregate effect that compounds the degradations experienced from such emanations, i.e., the impacted area outside of a region of dense base station deployment will typically be much larger than the impacted area around a single station. For the 10 MHz Low channel, several receivers were found to operate very well while others demonstrated performance degradation at several hundred kilometers.

Additionally, the ability to acquire or reacquire GPS in the presence of LightSquared ATC was measured for some users. Analysis showed the distance from the LightSquared transmitter to acquire or reacquire GPS signals was always greater than the distance where loss of GPS L1 tracking itself occurred. Testing indicated that loss of the ability to acquire or reacquire GPS signals occurred at distances anywhere between 2 and 4 times greater than initial loss of GPS L1 solution.

It should also be noted that for some applications detailed receiver outputs could not be obtained. E911 and Bureau of Land Management are examples where their reporting from live sky testing at Holloman AFB was simply that at a given standoff distance the receivers stopped functioning or an erroneous position was output.

One final point concluded from these test efforts was confirmation that, for the LightSquared power levels tested, the LightSquared filters were able to satisfy their stated emission mask and constrain out of band LightSquared emissions to less than -100 dBW/MHz at 1559 MHz and above. Thus, for the LightSquared power levels tested, out-of-band emissions by LightSquared ATCs into the GPS band have been determined to *not* represent a significant interference source. Laboratory, anechoic chamber, and live sky testing confirmed that the primary sources of GPS receiver degradation are receiver front end overload and intermodulation interference generated in the antenna assembly or receiver that causes 3rd order intermodulation products to be formed in the GPS L1 band (for details see Task 5 in Appendix B).

Table 1. Distance in Kilometers for 1 dB Degradation Caused by a Single LightSquared Base Station

Application	Phase 0	Phase 1	Phase 2	10 MHz Low
Aviation	24.3 – 1.1	27.2 – 1.2	19.3 – 0.9	< 0.1
Maritime	NM	NM	NM	NM
High Precision** (Survey, Agriculture, Science)	TBR – 0.5	TBR – 6.8	TBR – 3.8	TBR -- < 0.1
Timing	NM	10.8	NM	NM
Space	121.6	305.5 – 19.3	NM	NM

**Data still being analyzed

Table 2. Distance in Kilometers for Loss of Satellite Tracking Caused by a Single LightSquared Base Station

Application	Phase 0	Phase 1	Phase 2	10 MHz Low
Aviation	10.8 – 0.4	12.2 – 0.5	8.6 – 0.3	< 0.1
Maritime	0.6-.2	1.6-.4	1.0-.3	< 0.1
High Precision (Survey, Agriculture, Science)	2.2 – 0.2	7.7 – 2.1	6.1 – 1.7	0.4 -- < 0.1
Timing	NM	< 0.1	NM	NM
Space	24.3	61.0 – 2.7	NM	NM

*NM- Not measured

Task 6: Simulation Activities

Simulation activities utilized the planned initial LightSquared network documented in Task 2, scenarios from Task 3, and susceptibility results from Task 5 to evaluate impacts to aviation and space applications.

An aviation impact assessment was undertaken using the initial LightSquared base station locations located in four markets. Assuming a maximum EIRP of 62 dBm per sector per carrier, the assessment indicated that aircraft avionics will experience interference levels over very large regions of the United States and some portions of Canada and Mexico for the Phase 0, Phase 1, and Phase 2 spectrum deployments that exceed the levels that the equipment is certified to tolerate. Of the subset of certified airborne GPS receivers tested, all appeared to demonstrate a tolerance to interference at the LightSquared frequencies that exceeds the applicable FAA and International Civil Aviation Organization (ICAO) standards by some amount. However, even when utilizing the measured interference tolerance of this small subset of equipment, the NPEF assessment indicates that the LightSquared Network initial deployment would cause severe operational impact over significant regions of the United States. For instance, Figure 2 depicts two contours where GPS would be unusable for an aircraft operating at 500 feet above the ground for two representative receivers subjected to the LightSquared Phase 0 and Phase 1 signals. A common airborne receiver used on transport-category aircraft would be unable to track any GPS satellites in the orange region, while both this receiver and a very popular general aviation airborne receiver would be unable to track any GPS satellites in the red region. Both receivers would be significantly degraded over much larger regions than depicted on the map. Additional analyses are contained in the RTCA LightSquared Report (DO-327[1]).

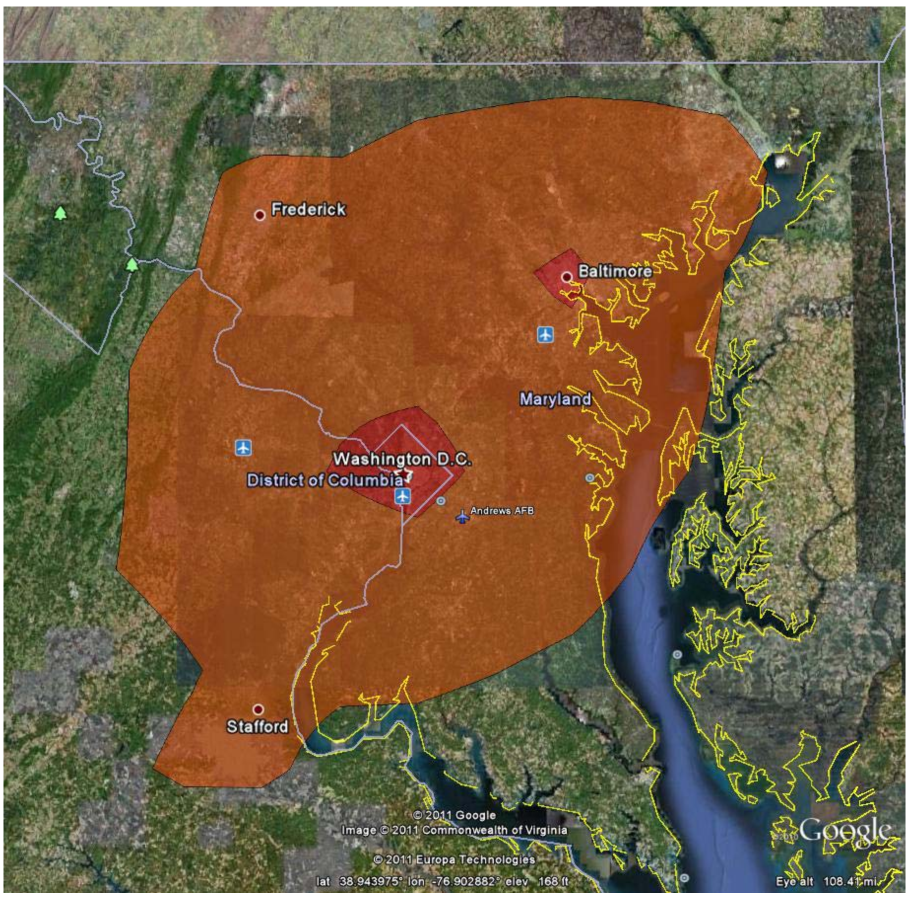

Figure 2. Upper Channel Received Power Levels 500 feet Above the Ground in the Baltimore-Washington Area for the Example LightSquared Network Deployment for Phase 0 or Phase 1.

[1] Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations, RTCA/DO-327, 3 June 2011

Simulation and analysis for space-based receivers was performed based on testing performed at JPL on current and future generations of space-based GPS receivers. Analysis was conducted to determine the percentage of time that space-based occultation measurements would be disrupted within a 10-day simulation. Results indicated that, depending on the spacecraft orbit (orbits assumed were 400 and 800 kilometer orbits inclined at 72 degrees) and on assumed parameters for the LightSquared base stations, the percentage of time occultation measurements could be disrupted was on the order of 5-10% for the power levels planned for use by LightSquared, to as high as 12% if FCC authorized levels of transmit power are assumed. Note that these are outage percentages based on a 10-day period and that the outage percentages based only on when the spacecraft is in view of the United States would be significantly higher per satellite pass. Such degradation would represent a severe disruption of space-based GPS receivers for radio occultation measurement of the Earth’s atmosphere and other science purposes. GPS receivers used for typical spacecraft navigation purposes with zenith pointed antennas are affected to a lesser degree (< 3% degradation for the worst case).

For high-precision GPS receivers used for Earth sciences and other applications requiring precise measurements, analysis was conducted to determine the required minimum separation distance between a terrestrial high-precision GPS receiver and a single LightSquared base station where there would be no discernible effect on received C/No. Results of the analysis showed that separation distances for the two receivers tested, assuming several different propagation models, ranged from approximately 1.5 to 4 kilometers for one receiver type to approximately 3 to12 kilometers for the other receiver model tested. Both models tested are used in the International GNSS Service (IGS) network. Given the ATC deployment density anticipated with the LightSquared terrestrial network, it is unlikely that such separation distances could be assured.

High-precision receivers are also used in many state and local networks. The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service, manages a network of Continuously Operating Reference Stations (CORS) that provide Global Navigation Satellite System (GNSS) data consisting of carrier phase and code range measurements in support of three dimensional positioning, meteorology, space weather, and geophysical applications throughout the United States, its territories, and a few foreign countries. The sites are independently owned and operated. Each agency shares their data with NGS and NGS in turn analyzes and distributes the data free of charge. As of May 2010, the CORS network contains over 1,450 stations, contributed by over 200 different organizations, and the network continues to expand (See **Error! Reference source not found.**).

Figure 3. U.S. CORS Station Locations

Task 7: Work Plan, Test Planning & Field Test Activities

The testing discussed in Task 5 included participation by LightSquared personnel to observe and comment on test conduct. LightSquared visited both Zeta Associates Inc., who performed FAA sponsored aviation receiver tests, and JPL, who performed NASA sponsored space-based receiver testing. LightSquared visited White Sands Missile Range to observe chamber test conditions and also provided and operated a representative ATC base station in support of open-air ('live sky') testing conducted at Holloman Air Force Base. To ensure a high fidelity test, actual LightSquared filters with representative antennas and equipment were used to transmit the LightSquared signal. LightSquared did not identify or voice any concerns regarding any of the above described test configurations.

Task 8: Mitigation Measures Applicable to GPS Users

Four possible mitigation measures applicable to GPS were identified and assessed. These included:

- Additional filtering – adding filtering to GPS user equipment to suppress the LightSquared signals.
- Adaptive antennas – using adaptive array antennas to spatially suppress the LightSquared signals.
- GPS changes – increasing GPS and WAAS broadcast signal strength to compensate for the signal-to-noise degradation caused by the LightSquared Network.
- Operational solutions – keeping GPS users separated from LightSquared base stations and mobile subscriber handsets.

Of these measures, adding additional filtering was found to be the most viable but would most likely be costly where it could be applied and cannot be applied to all GPS users. Many fielded GPS receivers are self-contained or integrated into other products (e.g., mobile phones). For such equipment, it is likely to be more cost-effective to replace the equipment rather than modify a given unit. Some fielded GPS equipment that utilizes external antennas may be able to satisfactorily function with the addition of in-line filtering or a replacement antenna with additional self contained filtering. However, such add-on filtering solutions are not viable for a significant fraction of fielded equipment due to considerations such as performance (signal attenuation, increased thermal noise floor, phase and group delay variations with temperature and between frequencies, loss of narrow correlator benefits), cost, size, and weight. Further, in the case of the aviation application, the equipment and its installation procedure would also need to be recertified following the inclusion of an in-line filter.

For a new product, many additional degrees of freedom are opened for mitigation techniques. In this case, the entire receiver and antenna design could be optimized to meet an overarching set of requirements that included the need to tolerate high levels of out of band interference at the LightSquared frequencies. In addition to adding to the filtering distributed along the RF front-end signal path, there are other design modifications that may be necessary to facilitate coexistence with the proposed LightSquared network. These include the careful control of the unit's oscillator phase noise and spurs that may lead to reciprocal mixing problems, and the need to ensure that the signal path components do not saturate in the presence of the high-powered

LightSquared emissions. Unfortunately, redesign is not likely to result in the same level of performance provided by current receivers, especially those employing wide RF front-end passbands. Such receivers are expected to increase in usage and importance in the near future as GLONASS, Galileo, and Compass satellite navigation constellations plan to be interoperable with GPS.

Given the wide variety of operational uses for GPS, however, the design requirements on receiving equipment also varies widely and there are some applications for which a practical receiver design will **NOT** be possible once the added constraint of coexistence with 34,000 high-powered base stations broadcasting signals 20 MHz away from the L1 carrier is applied. High-precision equipment is among the most difficult to protect against the LightSquared emissions since these receivers typically process wideband GPS signals that require a wideband receiver passband and such equipment usually also has severe differential group delay requirements. For these types of receivers, filtering can typically significantly degrade or even destroy the very information required for the most demanding scientific and precision applications.

Task 9: Mitigation Measures Applicable to LightSquared

The NPEF examined several possible mitigation measures that could be implemented by LightSquared to reduce potential interference to GPS receivers while still providing a viable nationwide terrestrial broadband service as required by the FCC. Five possible mitigation measures were examined: 1) increasing the frequency separation of LightSquared's transmitted signal relative to the lower edge of the RNSS allocated band at 1559-1610 MHz (e.g., by using only the lower of the two proposed LightSquared channels); 2) reducing the transmitted power to reduce the magnitude of the interfering signal; 3) modifying the base station antenna (either by narrowing the vertical beamwidth or increasing the antenna tilt so that less area is covered by each transmitting antenna); 4) using exclusion zones to maintain a minimum separation distance where the installation is fixed; and 5) relocating the proposed LightSquared network operating frequencies to a band more suitable for high power terrestrial operations.

Of these possible mitigation techniques applicable to LightSquared, the two involving increased frequency separation present the most promise for the widest communities of GPS users. The mitigation technique that offers the greatest long-term benefit to the GPS community is the relocation of LightSquared's terrestrial operations to a band more suitable for such applications and less disruptive to adjacent band space services such as GPS.

Another approach examined involves limiting the LightSquared transmissions to the lower 5 or 10 MHz channel of their planned deployment. However, while this approach would protect a limited number of GPS applications other applications would still be susceptible to interference.[2] Using this approach it may be possible to protect classes of GPS receivers, primarily those with

[2] The 15 May 2011 report of the FCC Technical Working Group noted that their tests did not reflect the planned LightSquared power levels. In single frequency mode, the test sites operated at power levels of approximately 59 dBm EIRP per channel as opposed to the 62 dBm EIRP per channel currently planned for the initial commercial deployment. For two carrier tests, the MIMO gain will not be present, reducing the EIRP a further 3 dB per channel to approximately 56 dBm EIRP. It is not adequate to merely adjust the standoff distances to account for greater power because this does not account for intermodulation products which might be introduced at the highest radiated power. The effects shown with respect to GPS may have to be adjusted in further tests to reflect planned operating conditions.

greater receiver selectivity. However, some classes of GPS receivers would still not be protected under this mitigation technique. Receivers having wider RF front-end characteristics, such as those used for scientific and commercial uses requiring high precision measurements, and some receivers capable of receiving multiple signals from different GNSS systems (e.g., GLONASS) would remain susceptible. Additionally, the use of only the lower LightSquared channel would provide only a temporary solution to the existing interference problems as 4G LTE levels of service may not be possible. Thus, even if allowed, the FCC's objectives and service conditions on the LightSquared license would not be met.

Recommendations

Based on analysis described in the main body of this Report, the NPEF has developed the following recommendations for ESG consideration.

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At the conclusion of this NPEF effort significant concerns remain that operation of an ATC integrated service as originally envisioned by the FCC *cannot* successfully coexist with GPS. Until the FCC granted a conditional waiver to LightSquared in January 2011, operation of terrestrial services under the MSS ATC regime had been coupled with the MSS satellite service so that the MSS L-band remained primarily a limited power space service downlink band that ensured compatibility with adjacent band space services such as GPS. Rigorous analysis of systems compatibility had also been impossible prior to now due to non-availability of relevant commercial ATC equipment. As with recommendation #2, this recommendation suggests there's need for additional assessment of previous rulemaking to determine if authorized ATC architectures in the MSS L-band could be tolerated by GPS applications in any form.

Appendix A: Assessment of LightSquared Terrestrial Broadband System Effects on Civil GPS Receivers and GPS-dependent Civil Government Applications

Task Statement

Assessment of LightSquared Terrestrial Broadband System Effects on Civil GPS Receivers and GPS-dependent Civil Government Applications

Scope

At the direction of the Executive Steering Group (ESG) of the National Executive Committee for Space-Based Positioning, Navigation, and Timing, herein referred to as the EXCOM, and with facilitation by the National Coordination Office (NCO), the National Space-Based PNT Systems Engineering Forum (NPEF) is tasked to conduct an assessment of the effects of LightSquared's planned deployment of terrestrial broadband systems to Global Positioning System (GPS) receivers and GPS-dependent systems and networks. The NPEF should engage with: 1) The LightSquared Working Group established at the direction of the Federal Communications Commission (FCC) and 2) GPS manufacturing and applications communities through relevant industry bodies (e.g. the U.S. GPS Industry Council and RTCA, Inc.). The NPEF is to investigate, assess, and determine the range of effects to GPS use based on operationally relevant scenarios that represent the current installed user base. While the NPEF tasks are to be conducted in cooperation with all involved entities to the extent possible, the NPEF is requested to produce an independent report to the ESG and EXCOM.

Background

Reference FCC Order DA 11-133, in the matter of LightSquared Subsidiary LLC "Request for Modification of its Authority for an Ancillary Terrestrial Component," adopted and released January 26, 2011 and NTIA January 12, 2011 letter to FCC Chairman.

Methodology and Assessment

1. Document LightSquared's Ancillary Terrestrial Component (ATC) and related user equipment signals and antenna specifications and characteristics, GPS receiver specifications and characteristics (e.g., Radionavigation-Satellite Service (RNSS) receiver characteristics submitted to the International Telecommunication Union (ITU)), and future spectrum environment considerations.

2. In cooperation with the LightSquared Working Group, develop a baseline model characterization of the planned initial and fully deployed broadband network, including ATC locations and siting assumptions/limitations. Identify user handset planning assumptions as appropriate.
3. In conjunction with federal and commercial GPS technical experts, develop operational scenarios representative of the full range of anticipated effects to GPS receiver use (including characterization by existing GPS receiver categories where possible) as well as deployed federal and commercial GPS-dependent systems or networks. The scenarios assessed shall consider federal and state government and commercial communities' current and planned use of GPS and GPS applications.
4. Develop appropriate metrics to quantitatively and qualitatively assess performance degradations from both technical and operational perspectives.
5. Analyze the expected and potential effects on GPS use for each of the developed scenarios including both current and future spectrum environment (e.g. 2025) considerations.
6. Coordinate simulation activities to further assess effects on GPS usage under various scenarios.
7. Coordinate work plan, test planning, and field test activities with the FCC, LightSquared, NTIA and the EXCOM departments and agencies to measure emissions and determine representative technical and operational GPS receiver effects as a function of distance from a LightSquared terrestrial base station
8. Assess potential mitigation techniques and their expected effectiveness/costs for various representative GPS receivers in each of the selected scenarios. Assessments should include analysis, simulation, and prototype testing (as practical).
9. Assess and recommend potential mitigation measures or techniques that are applicable to the LightSquared system based on the representative GPS receivers and the operational scenarios developed above including, for example, potential variations in emitted power, antenna gain pattern, and operating spectrum for the ATC base stations and mobile handsets.

Schedule and Deliverable

The NPEF is to complete the work under this Task Statement by May 31, 2011. An interim update will be provided to the ESG/EXCOM through the NCO Director by March 31, 2011. The final deliverable report will be produced in a publicly releasable version and For Official Use Only version as appropriate. The reports will detail the planned broadband system effects on GPS use and include details on potential technical and operational mitigation options for interoperability between the planned LightSquared network and federal and commercial GPS-dependent users, systems and networks. The report will include field measurements from the LightSquared ATC stations and mobile handset and an analysis of representative GPS receiver performance. Any classified concerns will be briefed to the NCO and ESG for discussion in an appropriate forum and venue. Issues of proprietary data will be handled on a case-by-case basis.

Appendix B: NPEF Tasks

***See companion pdf document.*