Experimental Evidence of Wide Area GPS Jamming That Will Result from LightSquared's Proposal to Convert Portions of L Band 1 to High Power Terrestrial Broadband

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Executive Summary

On November 18, 2010 LightSquared Subsidiary LLC filed an application requesting modification of its authority for Ancillary Terrestrial Component (FCC File No. SAT-MOD-20101118-00239) of L Band 1 MSS (Mobile Satellite Service). This application proposes to fundamentally change the usage of the L Band 1 spectrum (1525 MHz– 1559 MHz) from MSS (very low power, space to earth signals) to fixed, high power, terrestrial broadband service. The L Band 1 is adjacent to the GPS band (1559 MHz – 1610 MHz) where the GPS and other satellite based radio navigation systems operate.

If this modification is approved, widespread, severe GPS jamming will occur. In careful, experimental testing at Garmin using the technical details (power, frequency, modulation bandwidth) of the proposed LightSquared system, two common state-of-the-art Garmin GPS receivers experienced significant jamming within a radius of several miles from a simulated LightSquared transmitter.

The nüvi 265W, a very common portable consumer automotive navigation device, began to be jammed at a power level that represents a distance of 3.6 miles (5.8 kilometers) from the transmitter. **The nüvi 265W lost a fix at a distance of 0.66 miles (1.1 kilometers) from the transmitter.**

A GNS 430W, a common FAA certified General Aviation receiver that supports the FAA's NextGen RNAV and RNP operations, began to be jammed at a distance of 13.8 miles (22.1 kilometers) from the LightSquared transmitter. Total loss of fix occurred at a distance of 5.6 miles (9.0 kilometers) from the LightSquared transmitter. **This GPS receiver is certified for LPV (Localizer Performance with Vertical guidance) approach operations to 200 feet decision height, yet will be completely jammed by LightSquared transmitters over 5.6 miles (9.0 kilometers) away. Further, due to the special FAA requirements that this receiver is designed to meet, it takes on the order of 90 seconds to regain a fix once lost.**

Background

As discussed in the Executive Summary, LightSquared wants to fundamentally change the nature of L band 1 (1525 MHz – 1559 MHz) from a mobile, space to earth band containing very weak signals to a very noisy terrestrial broadband band full of extremely powerful signals. This will have a severe impact on the adjacent GPS band (1559 MHz – 1610 MHz) where GPS and other satellite navigation and augmentation systems operate (Glonass, Galileo, WAAS, etc).

LightSquared's published plans (ref LightSquared Letter to Marlene Dortch, November 18, 2010) entail the installation of up to 40,000 high power transmitters. These transmitters are authorized for up to 42 dBW (over 15,000 watts). **The operation of so many high powered transmitters so close in frequency to the GPS operating frequency (1575.42 MHz) will create a disastrous interference problem for GPS receiver operation to the point where GPS receivers will cease to operate (complete loss of fix) when in the vicinity of these transmitters.**

Garmin products represent over 90% of the installed navigation equipment in the General Aviation segment in the United States. Garmin also represents over 50% of the portable consumer automotive and handheld GPS devices sold in the United States. When faced with this potentially catastrophic interference threat, Garmin set out to quantify the jamming threat by carefully simulating the jamming scenario in the lab using high fidelity simulation equipment. Garmin tested two of our most popular devices. From the consumer automotive segment, testing was performed using a nüvi 265W, which is a popular member of a best-selling family of consumer automotive navigation devices. From the aviation segment, testing was performed using a GNS 430W, a receiver designed to meet the FAA TSO-C146a minimum performance specifications and which presently supports FAA's NextGen RNAV and RNP operations and is expected to be approved as a position source for FAA's NextGen ADS-B Out mandate.

Due to the accelerated schedule with which the FCC is processing LightSquared's request for waiver, only these two devices were tested in the interest of time. These devices are very representative of the installed user base of Garmin products in the United States.

Experimental Setup

The goal of these experiments was to use Garmin's engineering test lab to faithfully replicate the real-world scenario of LightSquared's proposed transmissions in the MSS band adjacent to GPS signals in the RNSS band. In general, care was taken to err in LightSquared's favor whenever assumptions were made about its transmissions. For example, Order and Authorization (SAT-MOD-20090429-00047, et. al.) released March 26, 2010 authorizes transmissions of 42 dBW EIRP (15.85 kW) with power allowed all the way to the band edge of 1559 MHz (paragraph 46); however, this test setup was based on LightSquared's verbal guidance (conference call between LightSquared and the USGPSIC (US GPS Industry Council), December 17th, 2010) that they would not transmit in excess of 32 dBW EIRP at 1555 MHz. Furthermore, the simulated GPS scenario used was comprised of strong signals and a stationary DUT (device under test) (no dynamics, fading, etc.).

LightSquared Transmitter Setup

Table 1 shows the constraints that were used to replicate LightSquared's transmissions in the MSS band. These were based on information that LightSquared provided to the USGPSIC on December 17, 2010. Once again, it is important to note that the upper band edge used for this experiment is only 1555 MHz, not 1559 MHz, which is the upper band edge of L Band 1 and would represent the worst case interference scenario.

TX Power (P_{TX})	62 dBm
Center Frequency	1552.5 MHz
Modulation	QPSK
Bandwidth	5 MHz
Transmit Antenna Gain (G_{AT})	0 dBi

Table 1: LightSquared Transmitter Specifications

In order to calculate the power incident upon one of the millions of deployed GPS navigation devices in the field at a given distance from the transmit tower, standard link budget and path loss equations for free space propagation were used. The power incident on the DUT (P_{DUT}) is equal to the transmit power (P_{TX}) plus the transmit antenna gain (G_{AT}) plus the path loss (G_{PL}, a negative quantity).

$$P_{DUT} = P_{TX} + G_{AT} + G_{PL}$$

Likewise, the free space path loss with respect to distance d and wavelength λ (in meters) is given by:

$$G_{PL} = -20Log\left(\frac{4\pi d}{\lambda}\right)$$

The resultant P_{DUT} is shown with respect to distance in Figure 1.

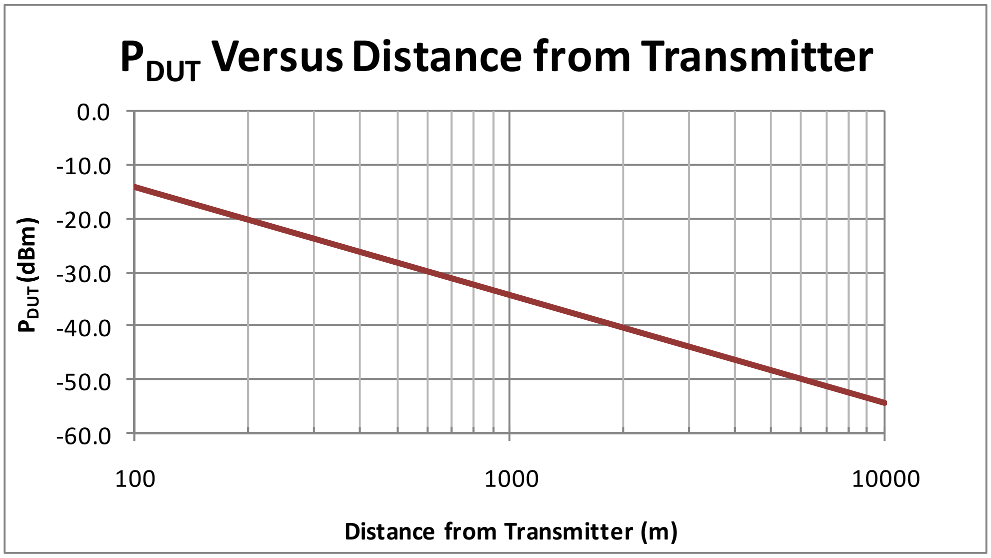

Figure 1: P_{DUT} Versus Distance from Transmitter

Experimental Setup in the Anechoic Chamber

As stated earlier, the goal of these tests was to emulate LightSquared's transmitter in a controlled laboratory environment. Consequently, the test setup was designed to allow the DUT to experience the same power levels seen in Figure 1 while simultaneously receiving ideal simulated GPS signals. An RF shielded room / anechoic chamber was used to create a test environment free from reflections and outside interference. In addition, calibrated antennas and state of the art test equipment were used to create the best possible test with the information available to date.

LightSquared Transmitter Simulation Setup

LightSquared's signal was simulated according to the parameters described above in Table 1 using a Rhode and Schwartz SMIQ-03S signal generator with digital modulation. This signal was then amplified with an Amplifier Research linear 5W amplifier (Model #5S1G4) to achieve the signal strengths needed to run the test. The output of the amplifier was padded by 10 dB and then run through a notch filter centered at 1575.42 MHz to reject any in-band spurious emissions from the RF signal generator. A detailed list of test equipment is available upon request. An Agilent N9020A spectrum analyzer was used to measure the output power (P_{TX}) of the LightSquared Transmitter Simulator as illustrated in Figure 2.

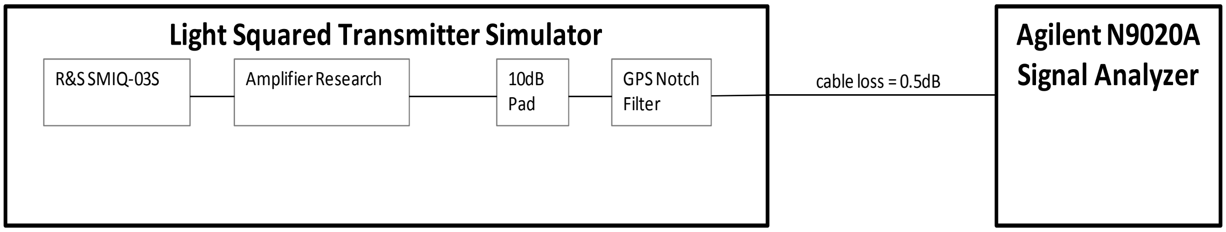

Figure 2: Transmitter Simulator Setup

Next, the output of the transmitter simulator was connected to a vertically polarized transmitting antenna located inside an RF anechoic chamber at exactly 3 meters from the DUT, as illustrated in Figure 3.

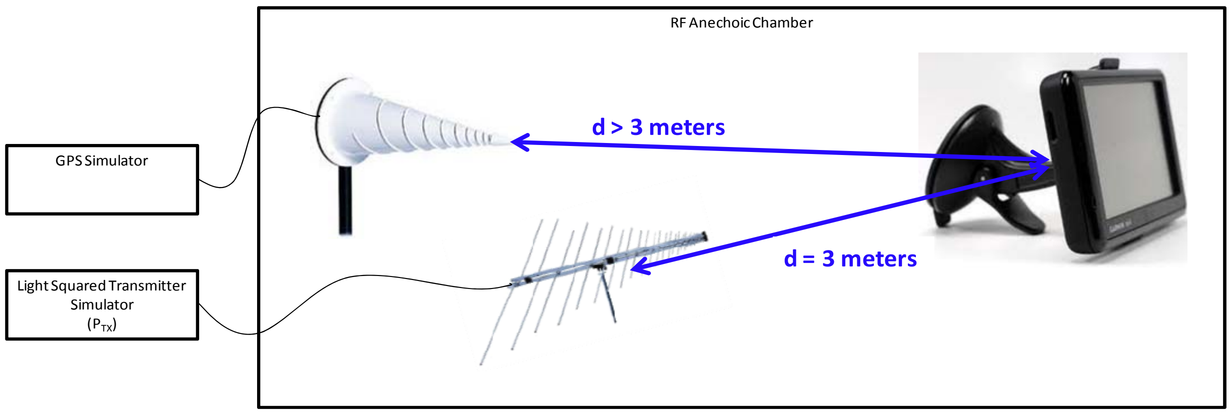

Figure 3: RF Anechoic Chamber Test Setup

Hence, the power incident upon the DUT (P_{DUT}) was controlled according to the following equation.

$$P_{DUT} = P_{TX} + G_{CABLE} + G_{AT} + G_{PL}(3m)$$

The free space path loss at 3 meters follows the path loss equation stated earlier such that $G_{PL}(3m) = -45.8dB$. Furthermore the Cable Loss (G_{CABLE}) was measured with a Network Analyzer as $G_{CABLE} = -2.56dB$ at 1552.5 MHz. Finally, the vertically polarized test antenna had a gain of $G_{AT} = 6.8dBi$ at 1550 MHz. These numbers were used to calculate the power incident upon the DUT and then a simulated path loss ($G_{PL\text{-}Simulated}$) was derived based on a LightSquared's stated transmit power of 62dBm (32dBW) and assumed antenna gain of 0dBi. This simulated path loss was then used to calculate the simulated distance from the LightSquared transmitter by the following equation.

$$d = \frac{\lambda}{4\pi} 10^{-\left(\frac{G_{PL-Simulated}}{20}\right)}$$

The test results shown henceforth throughout this document are based upon this setup. The actual jamming levels were measured during the experiment and then used to calculate the apparent distance from LightSquared's transmitter.

GPS simulation setup

The GPS signals were simulated by a Spirent GSS 6560 GPS Simulator. A stationary scenario at location N39.0000 and W95.0000 was used. The GPS constellation simulated contained 31 GPS satellites, which is the number of GPS satellites currently active. The time was set to the current wall clock time and was allowed to run freely over the duration of the test to facilitate the acquisition of GPS signals by the devices under test.

An external LNA (Mini-Circuits PN ZHL-1217HLN) was used in series with a right-hand circularly polarized (RHCP) conical antenna in an RF anechoic chamber. The output signal of the Spirent was adjusted so that each DUT reported a signal strength of approximately 40 dB-Hz C/N_0.

This scenario is considered to be rather benign in that there is no acceleration or signal obscuration being simulated. A reported signal strength of 40 dB-Hz is considered to be a strong signal.

Units Tested

Due to the accelerated nature with which the FCC is considering LightSquared's request for modification of its ATC authorization, there was not an abundance of time with which to test. In the interest of time, Garmin selected two common units, a nüvi 265W and a GNS 430W-- one from the Consumer Automotive business segment and one from the Certified Aviation segment.

The nüvi 265W is representative of Garmin's family of PNDs (Portable Navigation Devices). Tens of millions of devices similar to the nüvi 265W have been sold in the past few years in North America. It is also representative of the technology used by other manufactures of PND's, SmartPhones, and other portable GPS units. It is designed using a state of the art antenna, preselect filter, LNA, post-LNA filter and GPS demodulator. It is a high sensitivity, multi-channel design.

The GNS 430W is one of a number of FAA-certified navigation devices produced by Garmin that utilize a common GPS/SBAS receiver designed to meet the FAA TSO-C146a and TSO-C145a minimum performance specifications documented in RTCA DO-229C. As of December 31, 2010, Garmin has produced and shipped 57,812 FAA-certified products that utilize this GPS/SBAS receiver design. These products are installed in an estimated 43,321 aircraft worldwide. Garmin estimates that 70% of these products and aircraft are in the United States.

Test Results

<u>Nüvi 265W Jamming</u>

Table 2 describes the effect of jamming on the nüvi 265W. "Jamming is Detected" refers to the point at which the receiver experiences 1 dB of de-sensitization. "Loss of Fix in the Urban Canyon" refers to the point at which the receiver experiences 10 dB of de-sensitization. In Garmin's judgment, this much loss of signal in a challenging urban canyon environment would typically result in a loss of GPS service. "Loss of Fix in the Open Sky" refers to the point at which the GPS receiver lost its fix completely.

Effect	Distance
Jamming is detected	**3.57 miles (5756 meters)**
Loss of Service in the Urban Canyon	**1.79 miles (2884 meters)**
Loss of Fix in the Open Sky	**0.66 miles (1059 meters)**

Table 2: nüvi 265W Results

<u>GNS 430W Jamming</u>

Table 3 describes the effect of jamming on the GNS 430W. "Jamming is Detected" refers to the point at which the receiver experiences 1 dB of de-sensitization. "10 dB Loss of Sensitivity" refers to the point at which the receiver experiences 10 dB of de-sensitization. "Loss of Fix in the Open Sky" refers to the point at which the GPS receiver lost its fix completely.

Effect	Distance
Jamming is detected	**13.76 miles (22137 meters)**
10 dB Loss of Sensitivity	**9.85 miles (15853 meters)**
Loss of Fix in Open Sky	**5.60 miles (9018 meters)**

Table 3: GNS 430W Results

Conclusion

As shown by the Garmin testing described in this document, the proposed LightSquared plan to add 40,000 high-powered transmitters in the band adjacent to GPS will result in widespread, severe GPS jamming. This will deny GPS service over vast areas of the United States.