Performance Impacts of the LightSquared ATC Reference Stations on High Precision GPS Receivers

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NOAA / National Geodetic Survey
Presentation Overview

• LightSquared Background & Spectrum Plans
• NOAA Live Sky Summary Test Results
• NOAA Anechoic Chamber Test Results
• Present Status
Who is LightSquared?

- New Telecom company formed Mid 2010
  - Formerly SkyTerra and before that Mobile Satellite Ventures
- Company formed to create a nationwide 4G LTE (Long Term Evolution) open wireless broadband network
- First wholesale-only broadband network
- Intends to provide coverage to 92% of USA by 2015
- Key Asset
  - Mobile Satellite Service /Ancillary Terrestrial Component license for 1525–1559 MHz; 1626.5-1660.5 MHz
Illustration of Concerns with LightSquared

Situation before LightSquared

- low power (on Earth) satcom emissions

Situation with LightSquared

- 1.5 kW base station emissions

- GNSS receiver filter response
Original LightSquared Spectrum Plan

- L Band Satellite (Downlink)
- Aeronautical Radio navigation/ Radio navigation-Satellite (GPS, 51MHz)
- Big LEO (Uplink)
- L Band Satellite (Uplink)
- L Band Satellite Downlink (34 MHz)
- RNSS band (GPS, 51MHz)
- LTE (5)
- LTE (10)
- L1

Phase 0/1
- 1525
- 1559
- 1610
- 1626.5
- 1660.5

Phase 2
- 1526
- 1536
- 1545.2
- 1555.2
- 1610
NOAA /NGS Configuration For Live Sky Tests at Holloman AFB, April 15, 2011

- Four high precision geodetic / survey GPS receivers connected through an eight way splitter to a geodetic antenna using magnetic mounts on the vehicle roof
- Another antenna similarly mounted was connected to a single survey receiver with the manufacturer recommended geodetic antenna
- Due to high wind conditions on April 15th, the LightSquared Ancillary Terrestrial Component (ATC) reference station could only be raised to 32 ft (9.8 m) instead of the 100 ft (30.48 m) specified operational height
- The NOAA vehicle was approximately positioned 315 m from the LightSquared transmitter for Tests #2, Test #3, and Test #4
Live Sky Tests w/ NGS Vehicle @ 315 m
From LightSquared ATC Transmitter

<table>
<thead>
<tr>
<th>Test #2 – 5 Mhz – High Band – Full Power</th>
<th>Event time (GPS)</th>
<th>Transmitted Power EIRP –Total (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Test</td>
<td>2:39:00</td>
<td>54.1</td>
</tr>
<tr>
<td>Added + 3dB to each port</td>
<td>2:42:00</td>
<td>57.1</td>
</tr>
<tr>
<td>End Test</td>
<td>3:09:00</td>
<td>57.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test #3 – 5 Mhz – Low Band – Full Power</th>
<th>Event time (GPS)</th>
<th>Transmitted Power EIRP –Total (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Test</td>
<td>3:25:00</td>
<td>57.2</td>
</tr>
<tr>
<td>End Test</td>
<td>3:40:00</td>
<td>57.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test #4 – 10 Mhz – Low Band – Full Power</th>
<th>Event time (GPS)</th>
<th>Transmitted Power EIRP –Total (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Test</td>
<td>3:54:00</td>
<td>57.2</td>
</tr>
<tr>
<td>End Test</td>
<td>4:09:00</td>
<td>57.2</td>
</tr>
</tbody>
</table>
## High Precision Receiver Performance with LightSquared Lower 10MHz Signal

<table>
<thead>
<tr>
<th>Receiver ID Code</th>
<th>Receiver Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver H07007B/A-ant</td>
<td>No SNR degradation or tracking loss</td>
</tr>
<tr>
<td>Receiver H07007A/C-ant</td>
<td>SNRs for all PRNs tracked decreased 11 dB at beginning of test and dropped another 4 dB at the end of test</td>
</tr>
<tr>
<td>Receiver H80708/B-ant. (in 4 seconds)</td>
<td>less than 4 PRNs tracked – no position solution for remainder of test</td>
</tr>
<tr>
<td>Receiver H92053/B-ant. (in 6 seconds)</td>
<td></td>
</tr>
<tr>
<td>Receiver H91389/B-ant. (in 22 seconds)</td>
<td></td>
</tr>
</tbody>
</table>
Receiver H07007A C/N0 (Signal-to-Noise Ratio) During Tests #3 and #4

Receiver H07007A with Geodetic Antenna C
L1 C/A PRN 7, 8, 11, 13, 17, 19, 24, 26 & 28
NOAA Vehicle Approximately 315 m from LightSquared ATC Reference Station (Tower at 9.8 m Elevation)
Post Processed Pseudorange and Carrier Phase Accuracy with LightSquared Transmitter On

Receiver H07007A / Antenna C - Position Error During LightSquared Transmitter Test #4 (10 Mhz Low Band 57.2 dBm)

<table>
<thead>
<tr>
<th>Receiver H07007A/C-ant. Test site #1</th>
<th>95% Predicted Position Accuracy</th>
<th>95% Measured Position Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 cm.</td>
<td>1.2 cm</td>
<td>Test # 4 (898 Data Points)</td>
</tr>
</tbody>
</table>
TWG Live Sky Tests in Las Vegas

• NOAA / NGS and several law enforcement agencies were the only federal organizations participating in the Lightsquared sponsored Live Sky Testing
  ❖ Law enforcement agencies conducted an operational test of their equipment

❖ NOAA /NGS conducted a more detailed evaluation of percent of tracking loss for each receiver during LightSquared transmissions and tracking loss ranges from the LightSquared ATC reference station for each receiver
Typical East – West NOAA / NGS Vehicle Test Track May 19 -20, 2011
High Percentage Tracking Loss - GPS Receiver H33451 – Resume Tracking @ 3753 m. from the LightSquared Transmitter
East – West Maximum
GPS Receiver Tracking Loss Distances

<table>
<thead>
<tr>
<th>Receiver ID</th>
<th>Tracking Loss Range - East</th>
<th>Tracking Loss Range - West</th>
</tr>
</thead>
<tbody>
<tr>
<td>H07007 w/ Antenna 2</td>
<td>1101 m.</td>
<td>1339 m.</td>
</tr>
<tr>
<td>H41591 w/ Antenna 5</td>
<td>1025 m.</td>
<td>1303 m.</td>
</tr>
<tr>
<td>H80708 w/ Antenna 5</td>
<td>No Tracking Loss</td>
<td>775 m.</td>
</tr>
<tr>
<td>H33451 w/ Antenna 5</td>
<td>1125 m.</td>
<td>3753 m.</td>
</tr>
<tr>
<td>H84576 w/ Antenna 5</td>
<td><strong>2012 m.</strong></td>
<td><strong>3995 m.</strong></td>
</tr>
</tbody>
</table>

May 19, 2011 – 5 MHz Upper Band

<table>
<thead>
<tr>
<th>Receiver ID</th>
<th>Tracking Loss Range - East</th>
<th>Tracking Loss Range - West</th>
</tr>
</thead>
<tbody>
<tr>
<td>H07007 w/ Antenna 5</td>
<td>520 m.</td>
<td>362 m.</td>
</tr>
<tr>
<td>H41591 w/ Antenna 1</td>
<td>1868 m.</td>
<td>2981 m.</td>
</tr>
<tr>
<td>H33451 w/ Antenna 1</td>
<td>1886 m.</td>
<td>3133 m.</td>
</tr>
<tr>
<td>H84576 w/ Antenna 1</td>
<td>2015 m.</td>
<td><strong>3151 m.</strong></td>
</tr>
<tr>
<td>H47596 w/ Antenna 1</td>
<td>1153 m.</td>
<td>2094 m.</td>
</tr>
<tr>
<td>H91389 w/ Antenna 1</td>
<td><strong>2027 m.</strong></td>
<td>2119 m.</td>
</tr>
</tbody>
</table>

May 20, 2011 5 MHz Upper & Lower Band
LightSquared & Federal Working Groups
Completed Activities

- TWG Final report filed with the FCC June 30
  - LightSquared also filed a modified deployment plan on the same date as the TWG report

- NPEF Final Report public version filed with the FCC on July 06

- RTCA report focusing on aviation receivers available to the public on the FCC website
LightSquared Modified Spectrum Plan

• LightSquared will commence terrestrial commercial operations only on the lower 10 MHz portion of its spectrum
  ❖ They will coordinate and share the cost of underwriting a workable solution with GPS manufacturers of legacy precision measurement devices that may be at risk
  ❖ A filter solution for the Lower 10 MHz band has been developed by Javad, Topcon, Hemisphere, Partron America and PCTEL in partnership with LightSquared for high precision receivers
Current LightSquared Spectrum Plan
End Spectrum State Undefined

L Band Satellite Downlink (34 MHz)
Aeronautical Radio navigation/Satellite (GPS, 51MHz)
Big LEO (Uplink)
L Band Satellite (Uplink)

L Band Satellite Downlink (34 MHz)
RNSS band (GPS, 51MHz)

Phase 0/1
1525-1531.3 MHz

Phase 2
1545.2-1555.2 MHz

LTE (10)
1526.3-1531.3 MHz

LTE (5)
1550.2-1555.2 MHz

L1
1575.42 MHz

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LTE (10)
1526.3-1531.3 MHz

LTE (5)
1550.2-1555.2 MHz

L1
1575.42 MHz
Javad Filter Response to Mitigate the Lower 10 MHz LightSquared Signal
New NPEF Testing at WSMR
Oct. 31 – Nov. 4, 2011

• Targeted Testing
  – Navigation/Cellular Devices
  – Low 10 MHz
  – Handset (LSQ Cell Phone) simulation to be included

• NOAA Participants
  • NOS / NGS – 4 Precision survey / geodetic receivers
  • NOS / Office of Coast Survey – 4 marine navigation receivers
  • NWS – 3 general location / navigation receivers and 1 timing receiver
NPEF Testing at WSMR
Oct. 31 – Nov. 4, 2011

- Testing focused on General Navigation / Location receivers and Cellular Devices
- 37 other receivers (including high precision receivers) were also tested
- NGS objective in participating in the White Sands Missile Range (WSMR) testing was to:
  - Test the best and worst performing receiver with a legacy “robust” antenna from the Live Sky tests (Holloman, April 2011 and Las Vegas, May 2011)
  - CORS management requested another receiver be added to the test suite
  - A Javad receiver from the NGS CORS Foundation network was also added with the possibility of testing a modified JAVAD antenna to mitigate the LightSquared lower 10 MHz signal
  - A total of six receivers were tested (four different manufacturers and two spares)
NOAA /NGS Configuration for the Lower 10 MHz at WSMR on Day One (10/31/2011) of Testing

- Five high precision geodetic / survey GPS receivers connected through an eight way splitter to a “robust” legacy geodetic antenna in the Anechoic Chamber

- A single survey receiver with the manufacturer recommended geodetic antenna at a different grid location in the chamber
Receiver 339 / Ant. #369/ SNR Degradation / LightSquared Lower 10 MHz Signal / Cycle #1 / WSMR Anechoic Chamber Tests

LightSquared Signal Level in dB

GPS Time in Hours 10/31/2011

Test Event TE1
PRN 2
PRN 4
PRN 8
PRN 9
PRN 12
PRN 15
PRN 17
PRN 28

1 dB SNR Degradation

1 dB SNR Degradation

National Oceanic and Atmospheric Administration
Receiver 339 W/ #369 Geodetic Antenna / Radial Position Error / Test Event TE1 / Cycle #1 / WSMR Anechoic Chamber Tests

-42.4 dBm

GPS Accuracy in Meters - Point Position Solution

Light Squared signal in dBm

Radial Position Error_LT
Radial Position Error_RT
Test Event TE1
1 dB SNR Cycle #1DN
1 dB SNR Cycle #1UP

Tracking Loss

GPS Time in Hours 10/31/2011
Receiver 369 / Ant. #369 / SNR Degradation / LightSquared Lower 10 MHz Signal / Test Event TE1 / Cycle #2 / WSMR Anechoic Chamber Tests

LightSquared Signal Level in dBm

GPS Time in Hours 10/31/2011

-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 55 60

Test Event TE1 Signal
PRN 2
PRN 4
PRN 5
PRN 9
PRN 12
PRN 17
PRN 25
PRN 28
PRN 29

1 dB SNR Degradation
1 dB SNR Degradation
Receiver 114 / Ant. # 369 / Radial Position Error / Test Event TE1
Cycle # 1 / WSMR Anechoic Chamber Tests

GPS Accuracy in Meters - Point Position Solution

LightSquared Signal in dBm

Radial Position Error
LightSquared Test Signal (Ramp)
1 dB - SNR Degradation
1 dB - SNR Degradation

GPS Time in Hours 10/31/2011

-28.4 dBm
# GPS WSMR Receiver Performance

<table>
<thead>
<tr>
<th>Receiver ID</th>
<th>Antenna MR/ LR-More/Less Robust</th>
<th>1 dB SNR Avg. dBm</th>
<th>Test Day</th>
<th>GPS Accuracy Events</th>
<th>Tracking Loss</th>
<th>Test Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 2 3</td>
</tr>
<tr>
<td>369</td>
<td>369-MR</td>
<td>-33.8</td>
<td>Day 1</td>
<td>1 3 1</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>369-MR</td>
<td>-14.7</td>
<td>Day 1</td>
<td>1 3 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>369-MR</td>
<td>-28.8</td>
<td>Day 1</td>
<td>2 3 3</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>339</td>
<td>369-MR</td>
<td>-42.3</td>
<td>Day 1</td>
<td>2 4 3</td>
<td>Cycle #1 Only</td>
<td></td>
</tr>
<tr>
<td>399</td>
<td>399- LR</td>
<td>-42.1</td>
<td>Day 1</td>
<td>3 3 3</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>219</td>
<td>369-MR</td>
<td>None</td>
<td>Day 3</td>
<td>2 2 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>234</td>
<td>369-MR</td>
<td>None</td>
<td>Day 3</td>
<td>2 2 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>399- LR</td>
<td>-25.2</td>
<td>Day 3</td>
<td>1 2 1</td>
<td>All Cycles</td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>399- LR</td>
<td>-55.4</td>
<td>Day 3</td>
<td>2 2 0</td>
<td>All Cycles</td>
<td></td>
</tr>
<tr>
<td>231</td>
<td>399- LR</td>
<td>-41.9</td>
<td>Day 3</td>
<td>3 2 2</td>
<td>All Cycles</td>
<td></td>
</tr>
</tbody>
</table>
Anechoic Chamber Conclusions

• Preliminary Test Results indicate that the legacy “robust” antenna combined with a number of high precision receivers is not sufficient to mitigate the LightSquared lower 10 MHz signal
  ▶ Significant degradation to point position accuracy during all cycles of the LightSquared ramp test signal
  ▶ A filter solution developed specifically for the lower 10 MHz is required and needs to be independently tested
    ➢ The Javad modified filter was not available for WSMR Anechoic Chamber testing last November
Present Status

- The NPEF test report focusing on General Location and Navigation devices is under review and will be released to the public shortly.
- Based on the test results for General Location and Navigation receivers and aviation analysis, the EXCOM has notified the NTIA that further testing is not warranted at this time.
Questions?

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Backup Slides
US Space-Based PNT Organization Structure

WHITE HOUSE

NATIONAL EXECUTIVE COMMITTEE FOR SPACE-BASED PNT

Executive Steering Group
Co-Chairs: Defense, Transportation

NATIONAL COORDINATION OFFICE
Host: Commerce

ADVISORY BOARD
Sponsor: NASA

Defense
Transportation
State
Interior
Agriculture
Commerce
Homeland Security
Joint Chiefs of Staff
NASA

GPS International Working Group
Chair: State

Engineering Forum
Co-Chairs: Defense, Transportation

Ad Hoc Working Groups
JAVAD & TOPCON Filter Results
Alcatel Lucent Bell Labs

JAVAD C/N₀ vs Basestation Interference Signal Level

- Unmodified
- Modified

TOPCON C/No vs Basestation Interference Signal Level

- Unmodified
- Modified