LightSquared Can Complement GPS

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JAVAD GNSS

Presentation to PNT Board
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Crowne Plaza Hotel, Alexandria, VA
Topics

- Root of the technical problem
- Technical details of our solution
- Four ways to prove it works
- Interference analysis features
- Technology road map
Positioning

Navigation

Timing
Communication
Technical Problem
Cast of Characters

- LightSquared and Inmarsat
- GPS
- GLONASS

MHz:
- 1531
- 1550.2
- 1591
- 1610
- 1631.5

Signal Power:
- LightSquared 10L
- LightSquared 10H
- Normal MSS Signal Power (StarFire/Omnistar)
- GPS Signal Power
- GLONASS Signal Power
- GPS Filter for Older High Precision Receiver
- GPS Filter for Modern High Precision Receiver
- GNSS Filter for Modern High Precision Receiver

Frequency Ranges:
- 1526-1536 1545-1555 1563.42 1587.42 1590-1614 1626-1636
<table>
<thead>
<tr>
<th>DB Chart</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>10db</td>
<td>10</td>
</tr>
<tr>
<td>20db</td>
<td>100</td>
</tr>
<tr>
<td>30db</td>
<td>1,000</td>
</tr>
<tr>
<td>40db</td>
<td>10,000</td>
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<tr>
<td>50db</td>
<td>100,000</td>
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<tr>
<td>60db</td>
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<td>70db</td>
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<tr>
<td>140db</td>
<td>100,000,000,000,000</td>
</tr>
</tbody>
</table>
LSQ Power:
1/10 mw - 10 dBm

GPS Military & C/A Power:
1/20,000,000,000,000 mw - 133 dBm

GPS Encrypted P-Code Power:
1/200,000,000,000,000 mw - 143 dBm
LSQ Is 20 Trillion Times Stronger (133 dB)
Even small interference can hurt Defenseless GPS Receivers

GPS Receivers with No Protection
Tests

1. Component analysis and simulation
2. Sine wave in-circuit measurements
3. Anechoic chamber (more than NTIA)
4. The ultimate test
1. Component analysis and simulation

(Old Filter System)
Frequency Response old LNA.

Frequency Response
Old Filter System
Group Delay old LNA.

Group Delay
Old Filter System
2. Sine Wave In-Circuit Measurements

(Old Filter System)
Old Filter System

Ceramic Filter

Gp=+33dB

For GPS L1
P1dB inp = -23.4 dBm
P1dB outp = +8.6 dBm

Poutp 1575 = -67 dBm
Poutp 1536 = +4.9 dBm
Poutp 1626.5 = +9.5 dBm

Pinp 1575 = -100 dBm
Pinp 1536 = -10 dBm
Pinp 1626.5 = -10 dBm

< GPS
< 10 L
< 10 R
A diagram showing a signal path from an antenna through a Ceramic Filter and LNA, with the following specifications:

**For GPS L1**
- **Gp** = +33 dB
- **P1dB inp** = -23.4 dBm
- **P1dB outp** = +8.6 dBm

Signal levels:
- **Pinp 1575** = -100 dBm < **GPS**
- **Pinp 1536** = -10 dBm < **10 L**
- **Pinp 1626.5** = -10 dBm < **10 R**
Saturated!
Solution
New Filter System
1. Component analysis and simulation

(New Filter System)
Frequency Response of the New Filter System
Group of the New Filter System

nsec

GHz
2. Sine Wave \textbf{In-Circuit Measurements} (\textit{New Filter System})
Tested for Closest Edges of 10L and 10R to GPS

LightSquared and Inmarsat

GPS

GLONASS

MHz

1531
1550.2

1591
1610

1631.5

LightSquared Signal Power

10L

10H

JAVAD LightSquared Filtering

GPS Filter for Older High Precision Receiver

GNSS Filter for Modern High Precision Receiver

GNSS Filter for Modern High Precision Receiver

Normal MSS Signal Power (StarFire/Omnistar)

GPS Signal Power

GLONASS Signal Power
New Filter System

New LNA

Innovation saved $10 too

< GPS
< 10 L
< 10 R

P_{inp} 1575 = -100 \text{ dBm}
P_{inp} 1536 = -10 \text{ dBm}
P_{inp} 1626.5 = -10 \text{ dBm}

For GPS L1
Gp = +33 dB
P_{1dB\ inp} = -40 \text{ dBm}
P_{1dB\ outp} = -8 \text{ dBm}

P_{outp} 1575 = -67 \text{ dBm}
P_{outp} 1536 = -68 \text{ dBm}
P_{outp} 1626.5 = -70 \text{ dBm}

Patent Pending
Six SAW Filters
In +10 dBm P1dB

GPS > Pimp 1575 = -100 dBm
10 L > Pimp 1536 = -10 dBm +10 dBm P1dB
10 R > Pimp 1626.5 = -10 dBm +8 dBm P1dB

Ceramic Filter

L1

LNA

SAW
For GPS L1

$G_p = +33\,\text{dB}$

$P_{1\,\text{dB\,inp}} = -40\,\text{dBm}$

$P_{1\,\text{dB\,outp}} = -8\,\text{dBm}$
Out

GPS > Poutp 1575 = -67 dBm
10 L > Poutp 1536 = -68 dBm
10 R > Poutp 1626.5 = -70 dBm
The RF Chain

GPS
10 L
10 R

ATT
SAW Filter
SAW IF Filter

IF AMP/MIX
ADC DRIVER

GPS L1 Channel

ATT
SAW Filter
SAW IF Filter

IF AMP/MIX
ADC DRIVER

ATT
SAW Filter
SAW IF Filter

IF AMP/MIX
ADC DRIVER

ATT
SAW Filter
SAW IF Filter

IF AMP/MIX
ADC DRIVER

1575 P=-67 dBm
1536 P=-68 dBm
1626.5 P=-70 dBm

1575 P=-56 dBm
1536 P=-54 dBm
1626.5 P=-67 dBm

1575 P=-57 dBm
1536 P=-58 dBm
1626.5 P=-63 dBm

1575 P=-53 dBm
1536 P=-57 dBm
1626.5 P=-60 dBm

174 P=-58 dBm
135 P=-62 dBm
225.5 P=-168 dBm

174 P=-49 dBm
136 P=-105 dBm
225.5 P=-122 dBm
GPS > 1575 P= -67 dBm
10 L > 1536 P= -68 dBm
10 R > 1626.5 P= -70 dBm
174 P = -49 dBm
135 P = -105 dBm
225.5 P = -122 dBm

174 P = -58 dBm
135 P = -162 dBm
225.5 P = -168 dBm
## Overall Results

<table>
<thead>
<tr>
<th>Relative to GPS+Noise</th>
<th>L1</th>
<th>10L</th>
<th>10R</th>
<th>L1-10L</th>
<th>L1-10R</th>
</tr>
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<tbody>
<tr>
<td>FRQ</td>
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<td>-10</td>
<td>-90</td>
<td>-90</td>
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<td>-68</td>
<td>-70</td>
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<td>3</td>
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<tr>
<td>Ceramic Filter</td>
<td>-68</td>
<td>-70</td>
<td>-73</td>
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<td>5</td>
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<tr>
<td>LNA</td>
<td>-50</td>
<td>-54</td>
<td>-57</td>
<td>4</td>
<td>7</td>
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<tr>
<td>splitter</td>
<td>-53</td>
<td>-57</td>
<td>-60</td>
<td>4</td>
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<tr>
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<td>-60</td>
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<tr>
<td>Mixer</td>
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<td>-105</td>
<td>-122</td>
<td>56</td>
<td>73</td>
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<tr>
<td>SAW Filter</td>
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<td>-162</td>
<td>-168</td>
<td>104</td>
<td>110</td>
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<td>Overall Gain:</td>
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<td>FRQ</td>
<td>L1</td>
<td>10L</td>
<td>10R</td>
<td>L1-10L</td>
<td>L1-10R</td>
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<tr>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>--------</td>
<td>--------</td>
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<tr>
<td>Ant Filter input</td>
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<td>-10</td>
<td>-123</td>
<td>-123</td>
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<td>-68</td>
<td>-70</td>
<td>-32</td>
<td>-30</td>
</tr>
<tr>
<td>Ceramic Filter</td>
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<td>-70</td>
<td>-73</td>
<td>-31</td>
<td>-28</td>
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<tr>
<td>LNA</td>
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<td>-54</td>
<td>-57</td>
<td>-29</td>
<td>-26</td>
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<tr>
<td>splitter</td>
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<td>-60</td>
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<td>-168</td>
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<td>10L</td>
<td>10R</td>
<td>P-10L</td>
<td>P-10R</td>
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<tr>
<td>------------------</td>
<td>---</td>
<td>-----</td>
<td>-----</td>
<td>-------</td>
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<tr>
<td>Ant Filter input</td>
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<td>-10</td>
<td>-133</td>
<td>-133</td>
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<td>-70</td>
<td>-42</td>
<td>-40</td>
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<td>Ceramic Filter</td>
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<td>-70</td>
<td>-73</td>
<td>-41</td>
<td>-38</td>
</tr>
<tr>
<td>LNA</td>
<td>-93</td>
<td>-54</td>
<td>-57</td>
<td>-39</td>
<td>-36</td>
</tr>
<tr>
<td>Splitter</td>
<td>-96</td>
<td>-57</td>
<td>-60</td>
<td>-39</td>
<td>-36</td>
</tr>
<tr>
<td>Attenuator</td>
<td>-99</td>
<td>-60</td>
<td>-63</td>
<td>-39</td>
<td>-36</td>
</tr>
<tr>
<td>SAW filter</td>
<td>-100</td>
<td>-102</td>
<td>-105</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Mixer</td>
<td>-92</td>
<td>-105</td>
<td>-122</td>
<td>13</td>
<td>30</td>
</tr>
<tr>
<td>SAW Filter</td>
<td>-101</td>
<td>-162</td>
<td>-168</td>
<td>61</td>
<td>67</td>
</tr>
</tbody>
</table>
3. Anechoic Chamber System Test (New Filter System)
TRIUMPH-VS Interference Analyzer Screen

GPS L1 -5.0(44.0);0.5;28.3;10) 2011-10-04 10:58, "All OFF" (In chamber)

3%, 60, I+ U- C+ B+ W+ G-

0.000 m, RG174/U

Patent Pending
TRIUMPH-VS Interference Analysis Screen

**Spectrum Analysis**

- **Start**
- **Stop**
- **Settings**
- **Summary**
- **Satellites**
- **Spectrum**

**10, No GNSS Data, 3%, 60, I+ U- C+ B+ W+ G-, 2011-10-04 10:58**

**All OFF**

<table>
<thead>
<tr>
<th>Bands</th>
<th>Interference Magn.</th>
<th>RMS of Magnitude</th>
<th>S/N loss (C/A)</th>
<th>S/N loss (P)</th>
<th>Number of sat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS L1</td>
<td>-5.0</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS L2</td>
<td>1.0</td>
<td>0.5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>GPS L5</td>
<td>-2.0</td>
<td>0.5</td>
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<tr>
<td>GLN L1</td>
<td>1.0</td>
<td>0.6</td>
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<tr>
<td>GLN L2</td>
<td>2.7</td>
<td>0.7</td>
<td></td>
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</tr>
</tbody>
</table>

**Spectrum settings:** Title: "All OFF". Receiver Name: "In chamber". Start 1 time(s) Every 5 min with 10 sample(s) after 5 Sec delay. Record to: Int+SD. What to record: GPS_L1, GPS_L2, GPS_L5, GLN_L1, GLN_L2, Satellites, Polar Plot, Summary, Data.

**GNSS settings:** Antenna: Ext, Elev. mask = 10°, AGC = 3%, IBIR: on, ASIC freq = 60, Track: GPS+GLN+GAL+SBAS.

**Power settings:** UHF=off, Comm=on, Bluetooth=on, WiFi=on, GSM/GPRS=off.
### Spectrum Analysis

10, 10°, 3%, 60, I+ U+ C+ B+ W+ G-, 2011-10-04 15:06, "GPS" (In chamber)

<table>
<thead>
<tr>
<th>Bands</th>
<th>Interference Magn.</th>
<th>RMS of Magnitude</th>
<th>S/N loss (C/A)</th>
<th>S/N loss (P)</th>
<th>Number of sat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS L1</td>
<td>-5.0</td>
<td>0.5</td>
<td>-2.4 (0.1)</td>
<td>1.0 (0.1)</td>
<td>9 / 9</td>
</tr>
<tr>
<td>GPS L2</td>
<td>1.0</td>
<td>0.5</td>
<td>-4.0 (0.0)</td>
<td>0.7 (0.1)</td>
<td>2 / 9</td>
</tr>
<tr>
<td>GPS L5</td>
<td>-1.9</td>
<td>0.7</td>
<td>---</td>
<td>---</td>
<td>0 / 0</td>
</tr>
<tr>
<td>GLN L1</td>
<td>1.0</td>
<td>0.6</td>
<td>---</td>
<td>---</td>
<td>0 / 0</td>
</tr>
<tr>
<td>GLN L2</td>
<td>3.0</td>
<td>0.6</td>
<td>---</td>
<td>---</td>
<td>0 / 0</td>
</tr>
</tbody>
</table>

**Spectrum settings:** Title: "GPS". Receiver Name: "In chamber". Start 1 time(s) Every 5 min with 10 sample(s) after 5 Sec delay. Record to: Int+SD. What to record: GPS_L1, GPS_L2, GPS_L5, GLN_L1, GLN_L2, Satellites, Polar Plot, Summary, Data.

**GNSS settings:** Antenna: Ext, Elev. mask = 10°, AGC = 3%, IBIR: on, ASIC freq = 60, Track: GPS+GLN+GAL+SBAS.

**Power settings:** UHF=off, Comm=on, Bluetooth=on, WiFi=on, GSM/GPRS=off.
**TRIUMPH-VS C/N0 Analysis Screen**

<table>
<thead>
<tr>
<th>SAT</th>
<th>EL</th>
<th>AZ</th>
<th>H</th>
<th>L1</th>
<th>P1</th>
<th>P2</th>
<th>L2C</th>
<th>L5</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS3</td>
<td>71↑</td>
<td>286</td>
<td>H</td>
<td>47</td>
<td>45</td>
<td>44</td>
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<td>--</td>
</tr>
<tr>
<td>GPS6</td>
<td>83^</td>
<td>338</td>
<td>H</td>
<td>48</td>
<td>45</td>
<td>44</td>
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<tr>
<td>GPS7</td>
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<td>306</td>
<td>H</td>
<td>47</td>
<td>31</td>
<td>31</td>
<td>45</td>
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</tr>
<tr>
<td>GPS16</td>
<td>58↓</td>
<td>138</td>
<td>H</td>
<td>47</td>
<td>33</td>
<td>33</td>
<td>--</td>
<td>--</td>
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<tr>
<td>GPS18</td>
<td>24↑</td>
<td>92</td>
<td>H</td>
<td>47</td>
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<td>43</td>
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<td>GPS19</td>
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<td>262</td>
<td>H</td>
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<td>45</td>
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</tr>
<tr>
<td>GPS21</td>
<td>32↓</td>
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<td>GPS22</td>
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<td>GPS25</td>
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<td>GPS8</td>
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</tr>
</tbody>
</table>
TRIUMPH-VS Interference Analyzer Features (6 Bands)

- Interference frequency
- Interference power
- Control voltage shape
- C/N0 loss
- Statistical data
# Anechoic Chamber Test Result of 10L

<table>
<thead>
<tr>
<th>10L Power</th>
<th>AGC Change</th>
<th>C/N0 Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 dBm</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>-4 dBm</td>
<td>-0.6 dB</td>
<td>None</td>
</tr>
<tr>
<td>-1 dBm</td>
<td>-4.3 dB</td>
<td>1 dB</td>
</tr>
<tr>
<td>+1 dBm</td>
<td>-9.4 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td>+3 dBm</td>
<td>-16.6 dB</td>
<td>4 dB</td>
</tr>
<tr>
<td>+4.5 dBm</td>
<td>-16.6 dB</td>
<td>6 dB</td>
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</tbody>
</table>
Anechoic Chamber Test Result of 10R

10R had no effect on GPS for the maximum power of 10R that we could generate (+4.5 dBm)
4. The **Ultimate** Test: Special Zero Baseline

*(New Filter System)*
Old/Wide LNA

16 dB Attenuator (Calibrator input) to LSQ LNA

Receiver

Receiver
### Comparative Performance

#### Zero Baseline Results (Carrier Phase), cm

<table>
<thead>
<tr>
<th>Calibrator</th>
<th>Off</th>
<th>On</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS L1</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>GPS L2</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>GLN L1</td>
<td>0.39</td>
<td>0.14</td>
</tr>
<tr>
<td>GLN L2</td>
<td>0.01</td>
<td>0.01</td>
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</table>

#### Zero Baseline Results (Code Phase), cm

<table>
<thead>
<tr>
<th>Calibrator</th>
<th>Off</th>
<th>On</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS P1</td>
<td>4.22</td>
<td>4.86</td>
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<tr>
<td>GPS P2</td>
<td>5.73</td>
<td>4.08</td>
</tr>
<tr>
<td>GLN P1</td>
<td>60.36</td>
<td>7.38</td>
</tr>
<tr>
<td>GLN P2</td>
<td>2.03</td>
<td>1.36</td>
</tr>
</tbody>
</table>
Aggregate Effect of 44,000 LSQ Transmitters on LEO Satellites
<table>
<thead>
<tr>
<th>LEO Satellites</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Each LSQ transmitter (EIRP) *</td>
<td>61.5  dBm</td>
</tr>
<tr>
<td>Side lobe</td>
<td>-20   dB</td>
</tr>
<tr>
<td>Aggregate of 44,000 transmitters</td>
<td>46    dB</td>
</tr>
<tr>
<td>Min path loss for lowest LEO (200 miles)</td>
<td>-146  dB</td>
</tr>
<tr>
<td>Effective power at LEO</td>
<td>-58.5 dBm</td>
</tr>
</tbody>
</table>

* Equivalent Isotropically Radiated Power
Measuring and Compensating for Group and Carrier Delays
Our GLONASS is as good as GPS

We dynamically and continuously calibrate GLONASS inter-channel biases with accuracy of 0.2 millimeter
We dynamically and continuously calibrate GLONASS inter-channel biases with accuracy of 0.2 millimeter.
Group and Carrier Delay Measurement Block Diagram

PATENT PENDING

TRIUMPH Chip

Code 15 MHz

LO1

LO2

Capacitive Coupling

Variable Attenuator

Antenna input
New LNA

GLN FRQ No.

Code Delay (m)
New LNA
Temperature (°C)

GPS L1 Carrier Delay (degree)
Technology Road Map
LightSquared-Protected: Protected by the above JAVAD LNA system. For all precision positioning applications. Multipath mitigation features preserved. November 2011

LightSquared-Compensated: Protected by the above JAVAD LNA system and dynamically compensated for group delay variations (better than 100 picosecond). For precision timing applications. March 2012

LightSquared-Integrated: Same as two above plus LightSquared communication module inside. June 2012
Made in San Jose, California
Made in the USA
You Can Conduct Your Own Tests

The technology is available, and I have 40 units here today.