JAVAD

# Presentation to the National Space-based PNT Advisory Board

**The National Space-based PNT Advisory Board** was formed under the Federal Advisory Committee Act (FACA) to advise the United States government per National Security Presidential Directive (NSPD-39), and represents the major sectors of the Global Positioning System (GPS) user community. It is a panel of independent experts **supported by two Administrations** with over **250 years of cumulative experience** with GPS applications.

On November 9 and 10 of 2011, Dr. Javad Ashjaee, CEO of JAVAD GNSS, presented technical details of an **innovate filter system** to PNT board and proved that **LightSquared 10L and 10R (handset) signals can impose no negative effect to GPS signals and performance.**

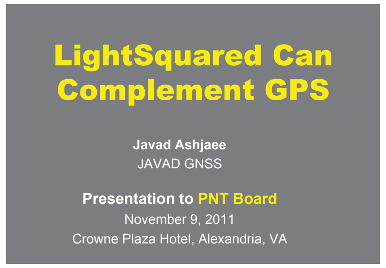
In both days Javad answered all technical questions posed by the **scientists of NASA, DoD, Air Force, academia, several GPS manufacturers**, and audiences present in meetings. The answers were convincing and, to our belief, no questions remained unanswered. We remain available to answer any further technical questions.

In this issue we present **slides presented in the two days of PNT meetings** and provide brief descriptions for each.

Our interest to LightSquared is not merely for the nationwide wideband system that it proposes to deploy and reach 260 million users. Of course all of us will benefit from this nationwide wideband, but our particular interest is for its **enormous positive impact in providing a reliable, fast, nationwide, and inexpensive communication system that it can provide for GNSS RTK and similar GNSS applications.**

LightSquared Compatible

**See www.javad.com**

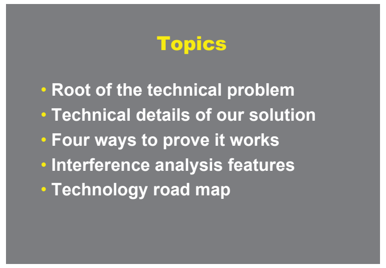


## LightSquared Can Complement GPS

**Javad Ashjaee**
JAVAD GNSS

**Presentation to PNT Board**
November 9, 2011
Crowne Plaza Hotel, Alexandria, VA

1) At the PNT meeting of November 9, 2011, in Alexandria, Virginia, we showed that LightSquared 10L (Base Station) and 10R (Handset) signals have absolutely no negative effect on GPS. Our solution also improves GPS performance.



**Topics**

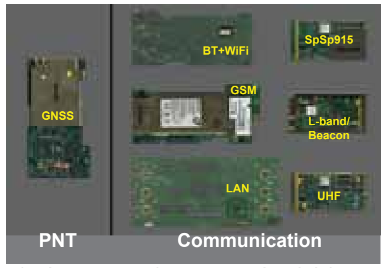
- Root of the technical problem
- Technical details of our solution
- Four ways to prove it works
- Interference analysis features
- Technology road map

2) We covered these topics in private meeting of November 8 and public meeting of November 9. Scientists from NASA, academia, and GPS manufacturers were present.

**Positioning**
**Navigation**
**Timing**

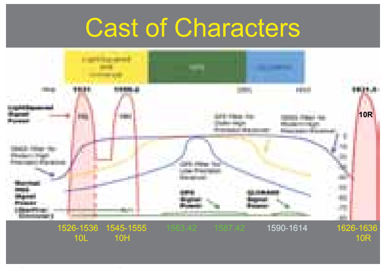
**Communication**

3) All positioning, navigation and timing devices also need the communication module. In the past 30 years we have perfected the PNT/GNSS module, but we still suffer from lack of a good communication system.



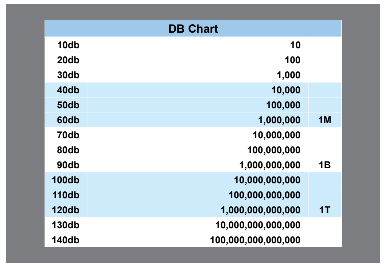
4) On the left is the GNSS/PNT module. The modules on the right are communication modules that we currently use in our GNSS devices. None are reliable, inexpensive and trouble free.

5) LightSquared can solve GNSS communication needs. We presented solution to make GPS compatible with LightSquared 10L and 10R (Handset) signals. We will test against 10H (Base Station High) later.



Cast of Characters

6) LightSquared signals are shown in red and GPS and GLONASS signals in green. The existing filters (purple, yellow, blue) do not provide any "fence" between LightSquared and GPS/GLONASS.



| DB Chart | | |
|---|---|---|
| 10db | 10 | |
| 20db | 100 | |
| 30db | 1,000 | |
| 40db | 10,000 | |
| 50db | 100,000 | |
| 60db | 1,000,000 | 1M |
| 70db | 10,000,000 | |
| 80db | 100,000,000 | |
| 90db | 1,000,000,000 | 1B |
| 100db | 10,000,000,000 | |
| 110db | 100,000,000,000 | |
| 120db | 1,000,000,000,000 | 1T |
| 130db | 10,000,000,000,000 | |
| 140db | 100,000,000,000,000 | |

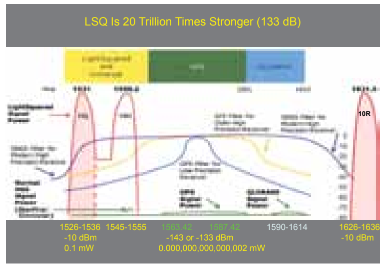
7) This dB chart shows relations between normal numbers and dB numbers. We use dB numbers to present the effect of our filter solution in the following slides.

**LSQ Power:**
1/10 mw -10 dBm

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

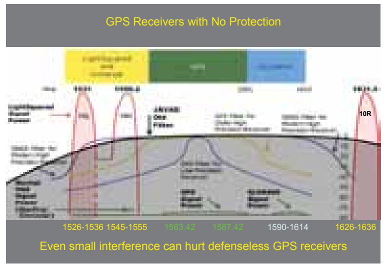
**GPS Encrypted P-Code Power:**
1/200,000,000,000,000 mw - 143 dBm

8) We assumed -10 dBm (0.1 milliwatt) for LightSquared 10L and 10R signals. This is higher than the maximum power that might ever be seen even next to a LightSquared transmitting tower.



LSQ Is 20 Trillion Times Stronger (133 dB)

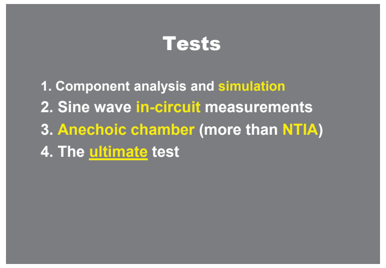
9) Even though GPS encrypted P-codes are 20 trillion times weaker than LightSquared signals, our solution provides for LightSquared signals to have no negative effect on GPS.



GPS Receivers with No Protection

Even small interference can hurt defenseless GPS receivers

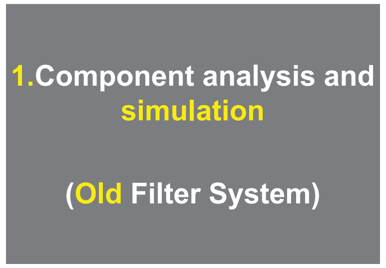
10) The shaded area is our old filter which provided no fence against LightSquared or any other signal near GPS. All LightSquared signals are well within the fence! This is typical of all manufacturers GPS filters.



**Tests**

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

11) We verified our innovative filter with four different tests. These tests cover everything from details of circuit design to the ultimate performance demonstrations like multipath mitigation features.



**1.Component analysis and simulation**

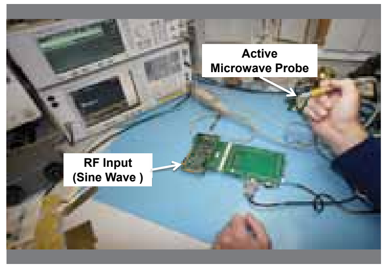
**(Old Filter System)**

12) Component Analysis test is to examine the electronic components to see if they can help to build the fence. This is like a cursor examination of the body of a patient.

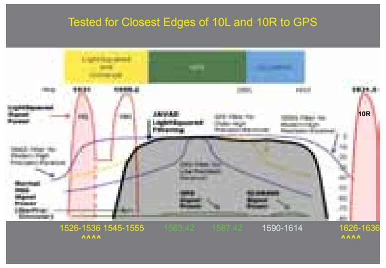
## 2. Sine Wave In-Circuit Measurements

## (New Filter System)

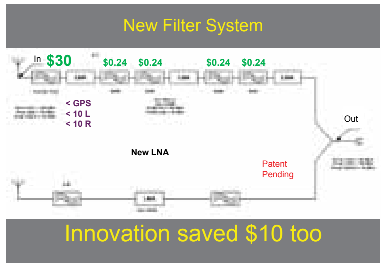
25) Next, we showed the sine-wave in-circuit test for the new filter. This is what we called “EKG” test.



26) Test set up for the in-circuit test. The EKG-type probe is shown in the hand of our engineer.


Tested for Closest Edges of 10L and 10R to GPS

27) We put the sine wave closest to the GPS signals both on the 10L and on the 10R side as shown by “^^^^^” symbols.

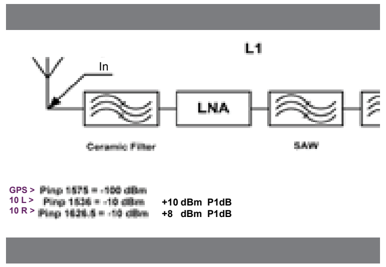

New Filter System

Innovation saved $10 too

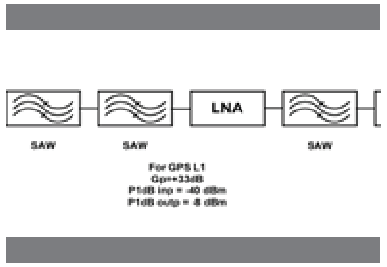
28) We replaced two ceramic filters ($40) with one ($30) and added four SAW filters ($1). We saved $10. This slide shows readings of sine wave powers of GPS, 10L and 10R frequencies as they pass through the new filter system.


Six SAW Filters

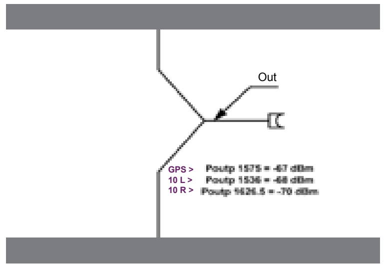
29) The relative size of SAW filters compared with a dime (US coin).



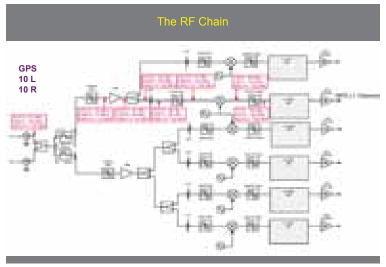
30) 1-dB compression point of the filter for 10L and 10R frequencies are +10 and +8 dBm, respectively. This means our filter can tolerate signals much stronger than 10L and 10R (20 dB and 18dB more!).



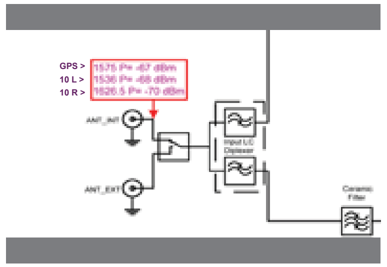
31) Zoom-in of the middle section of the new filter. 1-dB compression point for the GPS L1 is -40dBm at the input and -8dBm at the output. These do not concern 10L and 10R and shows the tolerance for in-band signals.



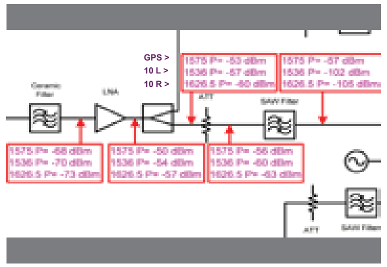
32) Zoom-in of the end of the filter system. GPS signal after passing this filter is 1dB higher than 10L and 3dB higher than 10R.


The RF Chain

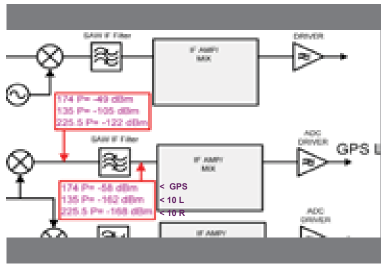
33) After filter system, signals go through the RF chain of the GPS receiver. This is the readings of GPS, 10L and 10R signals as they pass through 7 modules of the RF system. We will focus on the GPS L1 band.



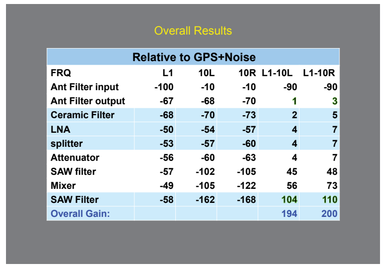
34) Zoom-in of the input section of the RF chain. The input powers shown, as provided by the filter system discussed earlier.



35) Zoom-in on the mid section of the RF chain showing strength of sine wave test signals. RF ceramic filter, LNA, splitter, attenuator, and SAW filter blocks are shown here.

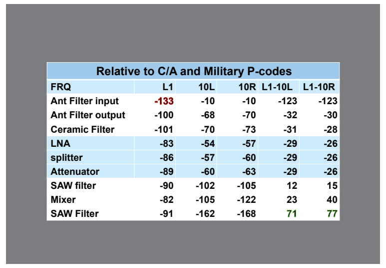


36) Zoom-in of the last section of the RF chain. Multiplexer and IF SAW filter blocks are shown here. 10L and 10R signals are completely gone (relative to the GPS signal). We summarize results in the next slide.


Overall Results

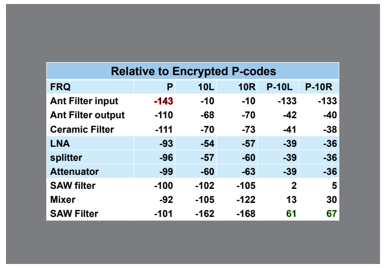
| Relative to GPS+Noise | | | | | |
|---|---|---|---|---|---|
| FRQ | L1 | 10L | 10R | L1-10L | L1-10R |
| Ant Filter input | -100 | -10 | -10 | -90 | -90 |
| Ant Filter output | -67 | -68 | -70 | 1 | 3 |
| Ceramic Filter | -68 | -70 | -73 | 2 | 5 |
| LNA | -50 | -54 | -57 | 4 | 7 |
| splitter | -53 | -57 | -60 | 4 | 7 |
| Attenuator | -56 | -60 | -63 | 4 | 7 |
| SAW filter | -57 | -102 | -105 | 45 | 48 |
| Mixer | -49 | -105 | -122 | 56 | 73 |
| SAW Filter | -58 | -162 | -168 | 104 | 110 |
| Overall Gain: | | | | 194 | 200 |

37) The right two columns show the relative strength of GPS compared to 10L and 10R as passes through different modules. 10L and 10R have completely disappeared at the end of our RF chain.



| Relative to C/A and Military P-codes | | | | | |
|---|---|---|---|---|---|
| FRQ | L1 | 10L | 10R | L1-10L | L1-10R |
| Ant Filter input | -133 | -10 | -10 | -123 | -123 |
| Ant Filter output | -100 | -68 | -70 | -32 | -30 |
| Ceramic Filter | -101 | -70 | -73 | -31 | -28 |
| LNA | -83 | -54 | -57 | -29 | -26 |
| splitter | -86 | -57 | -60 | -29 | -26 |
| Attenuator | -89 | -60 | -63 | -29 | -26 |
| SAW filter | -90 | -102 | -105 | 12 | 15 |
| Mixer | -82 | -105 | -122 | 23 | 40 |
| SAW Filter | -91 | -162 | -168 | 71 | 77 |

38) Relative strength of 10L and 10R compared to the pure GPS signals. Civilian users do not have access to the un-encrypted P-code and have to use its encrypted version which is much less effective.



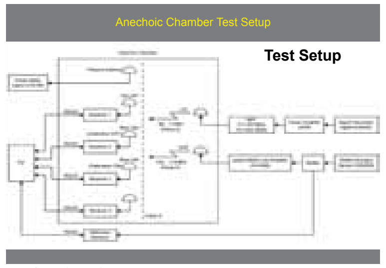
| Relative to Encrypted P-codes | | | | | |
|---|---|---|---|---|---|
| FRQ | P | 10L | 10R | P-10L | P-10R |
| Ant Filter input | -143 | -10 | -10 | -133 | -133 |
| Ant Filter output | -110 | -68 | -70 | -42 | -40 |
| Ceramic Filter | -111 | -70 | -73 | -41 | -38 |
| LNA | -93 | -54 | -57 | -39 | -36 |
| splitter | -96 | -57 | -60 | -39 | -36 |
| Attenuator | -99 | -60 | -63 | -39 | -36 |
| SAW filter | -100 | -102 | -105 | 2 | 5 |
| Mixer | -92 | -105 | -122 | 13 | 30 |
| SAW Filter | -101 | -162 | -168 | 61 | 67 |

39) Relative strength of 10L and 10R compared to encrypted P-code signals. Our filter makes even this weak GPS singal more than million times stronger than 10L and 10R. Filter does the job.

## 3. Anechoic Chamber System Test

## (New Filter System)

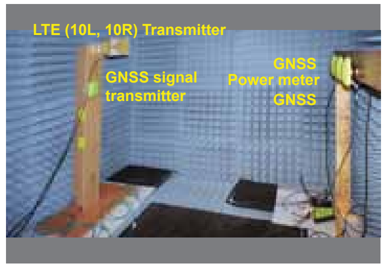
40) Next we focused on the Anechoic Chamber test of the new filter. This is like the stress test of the heart. Our Anechoic Chamber test is more comprehensive than NTIA tests.


Anechoic Chamber Test Setup

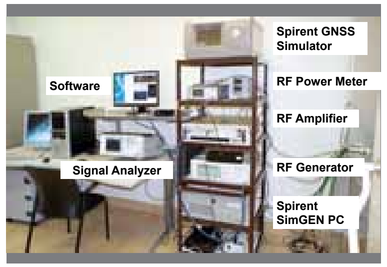
41) GPS, 10L and 10R signals are broadcast inside the sealed chamber and picked up by the GPS receivers under test. The sealed chamber and signal generators provide controlled environment for the test.

42) Signal generators and test equipment are outside the chamber and connected to the units under test inside the anechoic chamber.

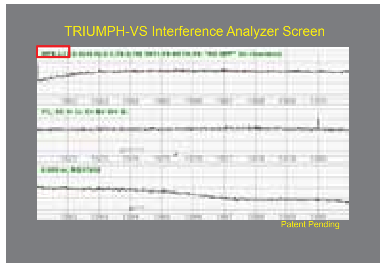
43) Close up of the anechoic chamber and the antennas connected to the GPS receivers. The power meter is a passive antenna that is used to measure the strength of signals near the GPS antennas.



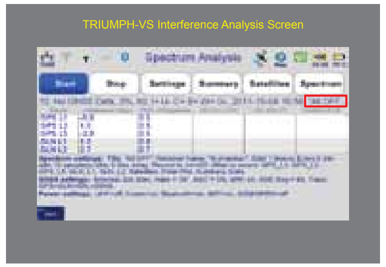
44) Inside the anechoic chamber. Generated signals are broadcast from the left side and picked up by antennas on the right side.



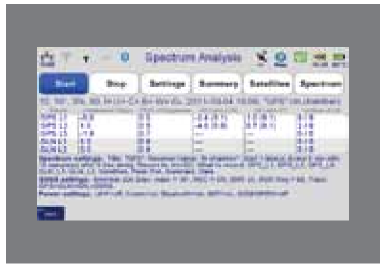
45) Test equipment outside the anechoic chamber. They generate GPS, 10L, and 10R signals and monitor the performance of the GNSS receiver inside the chamber.


TRIUMPH-VS Interference Analyzer Screen

46) Screen of Interferences Analyzer of TRIUMPH-VS. See www.javad.com for detailed description of this subject.


TRIUMPH-VS Interference Analysis Screen

47) Another screen of Interferences Analyzer of TRIUMPH-VS. See www.javad.com for detailed description of this subject.



48) Another screen of Interferences Analyzer of TRIUMPH-VS. See www.javad.com for detailed description of this subject.

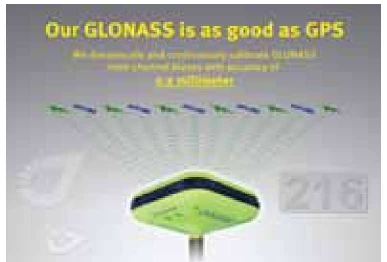
| LEO Satellites | | |
|---|---|---|
| Each LSQ transmitter (EIRP) * | 61.5 | dBm |
| Side lobe | -20 | dB |
| Aggregate of 44,000 transmitters | 46 | dB |
| Min path loss for lowest LEO (200 miles) | -146 | dB |
| **Effective power at LEO** | **-58.5** | **dBm** |

* Equivalent Isotropically Radiated Power

49) Even on the worst case, LightSquared signals have no effect on LEO satellites, which at worst case can see the -20 dB side lobes of the transmitters. The powers seen by LEO satellites are less than -58 dBm.

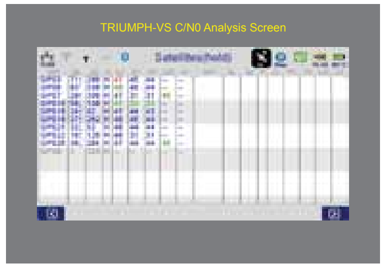
**Measuring and Compensating for Group and Carrier Delays**

50) Next we discussed our earlier innovation of measuring and compensating for group and carrier delay variations of filter systems which is particularly important for timing applications.


**Our GLONASS is as good as GPS**

51) We announced this innovation two years ago. This is one of our booth panels at 2009 ION conference.

TRIUMPH-VS C/N0 Analysis Screen



52) Another screen of Interferences Analyzer of TRIUMPH-VS. See www.javad.com for detailed description of this subject.

**TRIUMPH-VS Interference Analyzer Features (6 Bands)**

- Interference frequency
- Interference power
- Control voltage shape
- C/N0 loss
- Statistical data

53) Interference Analyzer features of TRIUMPH-VS. See www.javad.com for detailed description of this subject.

Anechoic Chamber Test Result of 10L

| 10L Power | AGC Change | C/N0 Loss |
|---|---|---|
| -10 dBm | None | None |
| -4 dBm | -0.6 dB | None |
| -1 dBm | -4.3 dB | 1 dB |
| +1 dBm | -9.4 dB | 2 dB |
| +3 dBm | -16.6 dB | 4 dB |
| +4.5 dBm | -16.6 dB | 6 dB |

54) Our filter systems can protect against 10L powers even with much higher powers than its authorized power. We stopped the test at +4.5 dBm because our transmitter could not generate higher powers.

Anechoic Chamber Test Result of 10R

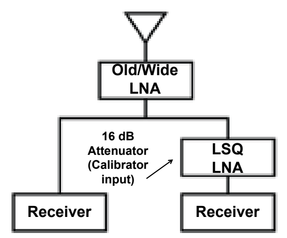
**10R** had no effect on GPS for the maximum power of 10R that we could generate (**+4.5 dBm**)

55) Anechoic Chamber test results on 10R. Our filter systems protects against powers much higher than the authorized power of 10L. There is absolutely no negative effect. Our AGC system could not even see any trace of 10R signal.

**4. The Ultimate Test: Special Zero Baseline**

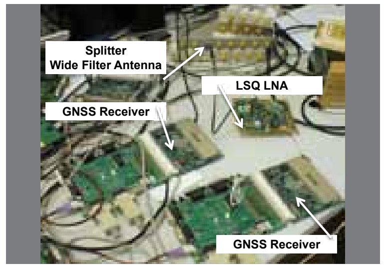
**(New Filter System)**

56) The impact on the accuracy and multipath mitigation capabilities of the new filter system. We call this "the ultimate test" because it can readily show any negative effect on the performance of the filter and the overall system.



57) Block diagram of the ultimate test. Signal from the same antenna is fed to our conventional receiver on the left and to the new filter system on the right. The comparison of the two provides the ultimate test!

58) Antenna is mounted in the marked location which is subjected to multipath from above and below the antenna.



59) Test set up inside the office. Antenna is routed to the left and the right. On the left is the old wide-band antenna. On the right is the new LightSquared compatible new filter system.

Comparative Performance

| Zero Baseline Results (Carrier Phase), cm | | |
|---|---|---|
| Calibrator | Off | On |
| GPS L1 | 0.02 | 0.02 |
| GPS L2 | 0.01 | 0.01 |
| **GLN L1** | **0.39** | **0.14** |
| GLN L2 | 0.01 | 0.01 |

| Zero Baseline Results (Code Phase), cm | | |
|---|---|---|
| Calibrator | Off | On |
| GPS P1 | 4.22 | 4.86 |
| GPS P2 | 5.73 | 4.08 |
| **GLN P1** | **60.36** | **7.38** |
| GLN P2 | 2.03 | 1.36 |

60) The zero-baseline result is 0.2 mm (0.007 inch). The total effect is smaller than the thickness of a business card! On/Off columns show group delay calibration helps GLONASS signals when it is ON. All units are in cm.

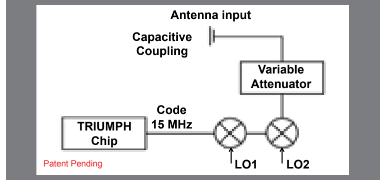
**Aggregate Effect of 44,000 LSQ Transmitters on LEO Satellites**

61) Next we calculated the effect of 44,000 Light Squared-transmitters on Low Earth Orbit Satellites. NASA was worried about such effects on their LEO satellites.

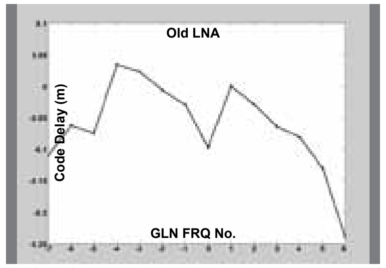
We dynamically and continuously calibrate GLONASS inter-channel biases with accuracy of 0.2 millimeter

62) Calibrating for GLONASS inter-channel biases is achieved by measuring the group and carrier delay variations.

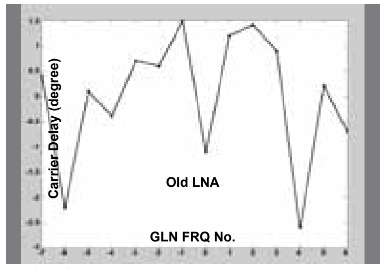
Group and Carrier Delay Measurement Block Diagram



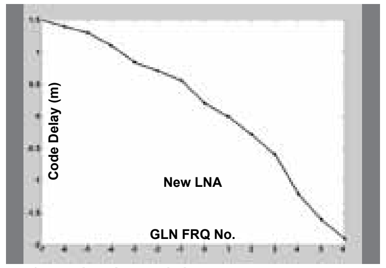
63) Block diagram of measuring group and carrier delay variation invention. We generate GPS and GLONASS like signals, send them up to the antenna, receive them back, and measure their travel times.



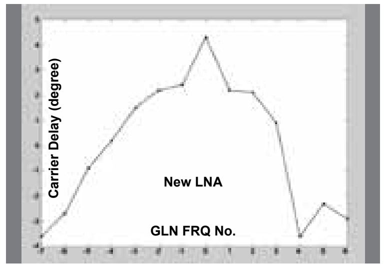
64) Group delay variations of different GLONASS satellites. Each GLONASS satellite is 500KHz away from its neighbor (maximum variation of 5.5 MHz).



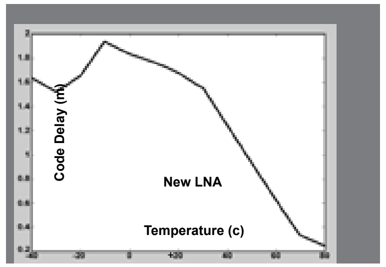
65) Carrier delay variations on different GLONASS satellites. We can use the same technique to compensate for carrier delay variations if Doppler shifts are significant for GPS in LEO satellites.



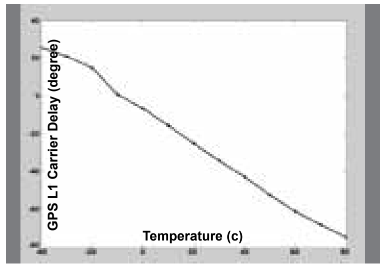
66) GLONASS group delay variations with new filter. We dynamically and continuously measure and compensate for group and carrier delay variations.



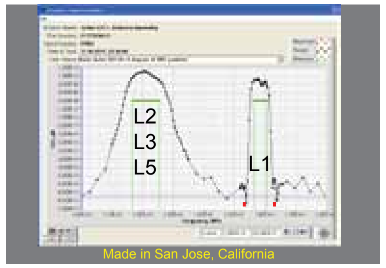
67) GLONASS carrier delay variations with new filter.



68) Group delays also vary due to temperature. Our group delay compensation technique is very helpful for timing applications too. We can automatically compensate for temperature variations.



69) Carrier delays also vary due to temperature. Our carrier delay compensation technique is very helpful for timing applications too. We can automatically compensate for temperature variations and provide Pico sends time transfer.



Made in San Jose, California

70) This is the manufacturing test sheet that goes with every antenna. At PNT meeting we had 40 LightSquared compatible antenna ready for those who wanted to take and do their own tests.

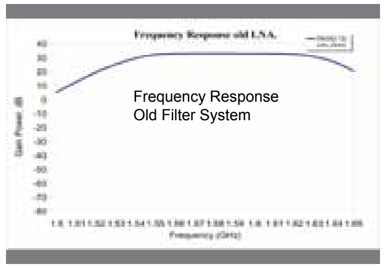
71) Our own manufacturing facilities in San Jose, California; in the heart of Silicon Valley. Our motto is "Silicon Valley is Back to Build".

**LightSquared-Protected:** Protected by the above JAVAD LNA system. For all precision positioning applications. Multipath mitigation features preserved. November 2011

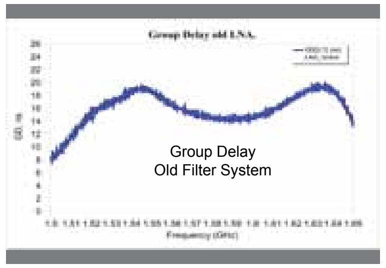
**LightSquared-Compensated:** Protected by the above JAVAD LNA system and dynamically compensated for group delay variations (better than 100 picoseconds). For precision timing applications. March 2012

**LightSquared-Integrated:** Same as two above plus LightSquared communication module inside. June 2012

72) Furtheremore by March 2012 we will release products for timing applications and by June 2012, we will introduce products integrated with LightSquared communication modules.



13) This is the shape of our old filter which shows the gate is wide open and cannot protect.

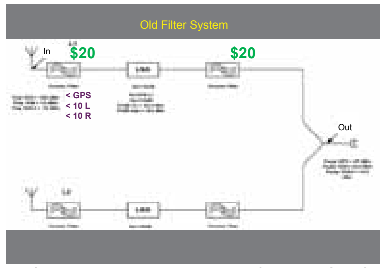


14) Group delay feature is not a critical item any more. This is just to show the group delay shape of our old filter system.

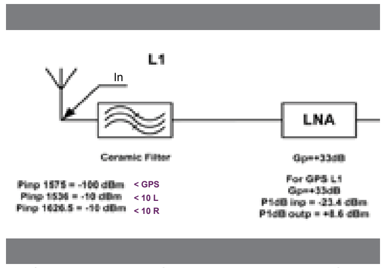
**2. Sine Wave In-Circuit Measurements**

**(Old Filter System)**

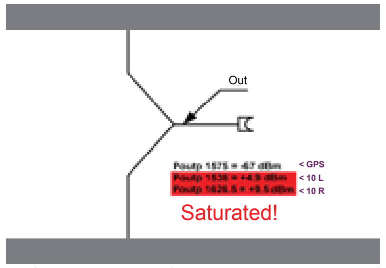
15) Sine wave in-circuit test is injecting signals and see the circuit performance in different sections. This is like attaching the EKG probes to the body of a person to examine the heart function in different parts of the body.



16) Probe readings of the GPS, 10L and 10R signals through our old filter system. The filter had 2 ceramic filters, $20 each.



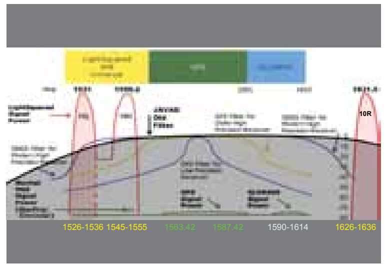
17) Zoom-in of the input part of the previous slide. Sine waves with the specified powers at GPS, 10L and 10R frequencies are injected to the input.



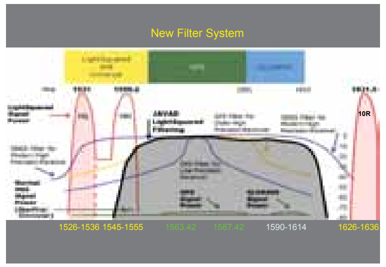
18) Zoom-in of the output part of the previous slide. Filter was not able to suppress 10L and 10R signals and the system is saturated. No need to do any further test. First two tests showed that our old filter system des not work.

**Solution**

19) Next we focused on explaining our solution and proving its performance with four different tests.



20) This is what the shape of the old filter. No fence! We need to design a filter which does not let 10L and 10 R in.

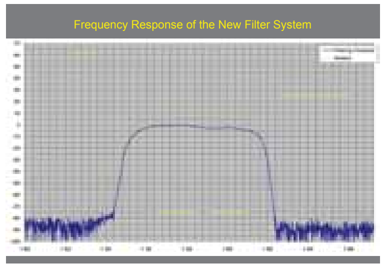


21) This is the shape of our new filter. It provides complete protection against 10L and 10R. We will show the results of four tests on this new filter in the following slides.

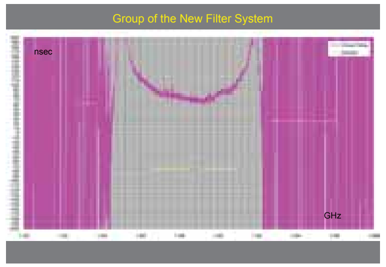
**1.Component analysis and simulation**

**(New Filter System)**

22) First is the component analysis test of the new filter system.



23) This is the shape of the new filter as seen by the Agilent signal analyzer. It looks good and promising to provide good protection. This by itself is not enough. See the result of the actual tests too.



24) We solved the effect of group delay variations two years ago when we invented a technique to address its effect on GLONASS FDMA. Similarly, we can compensate for the effects of large Doppler shifts on LEO satellites.

## Highlights

**We assumed LightSquared towers would transmit 0.1 milliwatt of power. This is higher than the maximum power that might ever been seen even next to a LightSquared transmitting tower.**

**We suppressed the power of the LightSquared signals by a factor of 200 dB (100,000,000,000,000,000,000 times), one hundred million trillions!**

**We proved that GPS receivers would not see any negative effect even if LightSquared transmits signals at even much higher powers.**

**The cumulative effect of all sources of error (including the effect of the new LightSquared Compatible filter system) is less than 0.2 millimeter (0.008 inch). This is less than the thickness of a business card.**

**Our innovation resulted in saving of about $10 in the component costs of our GNSS receivers.**

**The new filter system not only protects against LightSquared signals, but it also improves the performance of GNSS receivers against all other interferences that normally exist near GNSS receivers (e.g. harmonics of TV and radio stations or any other transmitter.**

**We employed four different test methods to prove these facts. These tests were: 1) Component analysis and simulation, 2) Sine wave in-circuit measurements, 3) Anechoic chamber tests, 4) the Ultimate test (a special version of zero-baseline test).**

**We took 40 of the manufactured units to demonstrate that our innovation is actually in full production and presentations were not a mere technical results in our laboratories. We also offered them to those who wanted to perform their own tests.**

**All we ship today are LightSquared compatible or eligible for free retrofit. We also offer to retrofit our existing receivers with the price of $300 to $800, depending on the model.**