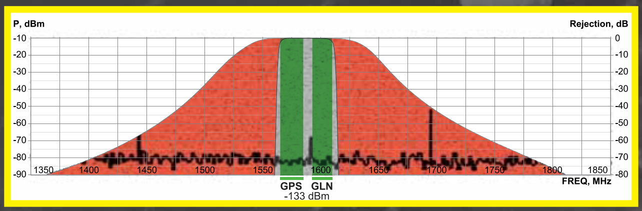
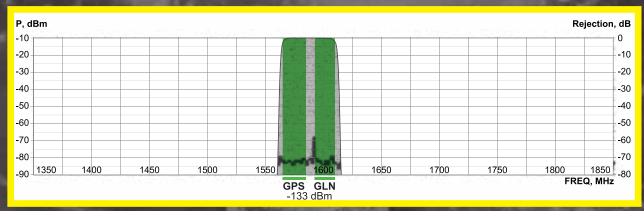
A technical story...

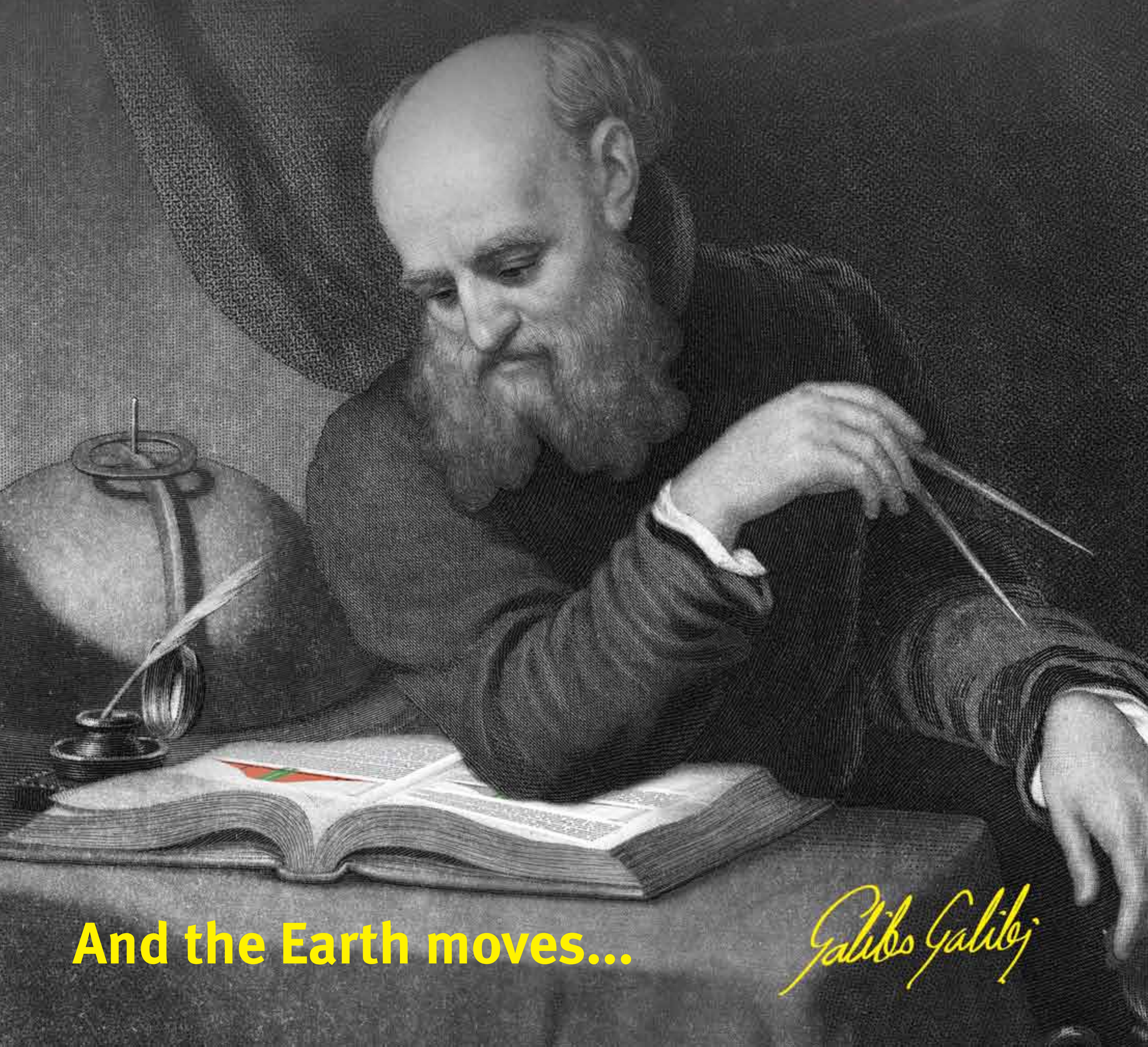
of a bad filter...



and a good filter...



which turned political!



And the Earth moves...

The Real Interference Issue: Political Noise

I have been reflecting on events related to the GPS interference issue and LightSquared. What I discovered revealed the root of this problem, and as I will describe in this paper, it is entirely caused by poor design of GPS receivers The problem can be solved easily and with existing technology. In fact, it already has been solved.

Unfortunately, the GPS interference issue is a perfect example of how Washington is allowing politics to influence a technical debate. Opponents of LightSquared are trying to deal with the GPS interference issue by employing armies of lawyers and lobbyists who either don't understand the scientific facts or are lying about them. Instead, it would be much better for those who are making much of the noise about LightSquared, to spend money on research and development to help solve the problem.

This political approach to a technical issue demonstrates why the United States is currently ranked seventh in the world for the most scientific and engineering researchers per capita, following Finland, Sweden, Japan, Singapore and Norway. Why would high-caliber talent want to go into technology-related jobs when our system appears to be placing low value on scientific facts and high value on political influence?

How I Came to Understand the Real Issue

Around December 2010, when I received initial reports and letters regarding LightSquared interference with GPS, I joined the Coalition to Save GPS and signed a letter to the chairman of the Federal Communications Commission thinking I was doing my part to protect GPS. I wrote similar commentary on my website, www.javad.com.

Then I was invited to participate in the 2011 ESRI[1] conference in San Diego and join a panel to discuss the LightSquared-GPS issues. In order to defend the GPS system and provide technical data, I started my own investigation of the problem. I soon realized that my own company had a fundamental problem in the first stage of our antenna system. It was allowing other radio energies into the receiver in addition to the Global Navigation Satellite System (GNSS) signals. I recognized that the flaw in our filter system would degrade the performance of our GNSS receivers whether LightSquared's system is deployed or not.

As an engineer, I always strive to innovate my products and took it upon myself to see if we could develop a device that filters out as much noise as possible from the adjacent band without affecting the integrity of the GNSS signals. Unfortunately, this was never a priority in our industry – we always used filters that offered little protection against interference.

I soon drew the conclusion that the standard operating procedure resulted in degraded performance. **Figure 1**, below, shows the theoretical spectrum of the United States' GPS satellite system and Russia's similar system, GLONASS, the so-called L1 bands. This figure shows GPS and GLONASS spectrum allocations and assumes that all of the adjacent spectrum is completely clean and free of any radio signals. At least that's the theory. In practice this is not the case.

[1]ESRI is a company based in Redlands, CA that creates Geographic Information Systems software and provides digital maps and other GIS data. They sponsor numerous conferences each year.

Figure 1: The Theoretical GPS Spectrum

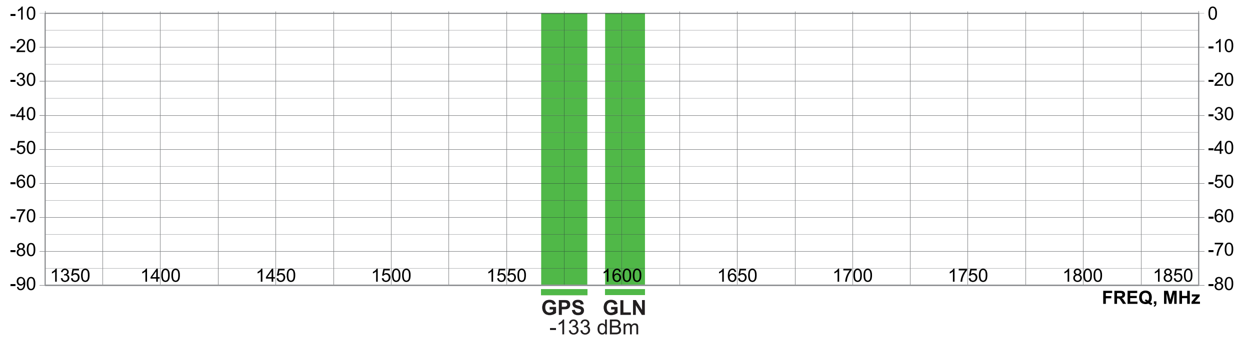


Figure 2, below, shows what the actual spectrum may look like. It has lots of “white noise” and harmonics of other existing transmitters. In the real world, the GPS system lives in a very noisy neighbourhood. The shape of interfering signals can change drastically as you drive around. To extract the best of GNSS signals, we should only allow these signals in and do not invite other outside noise.

Figure 2: The Real World GPS Spectrum

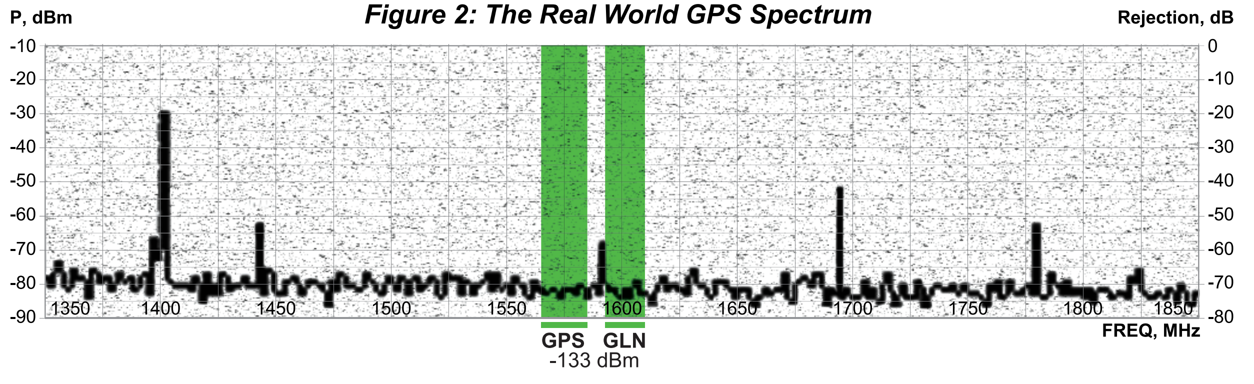
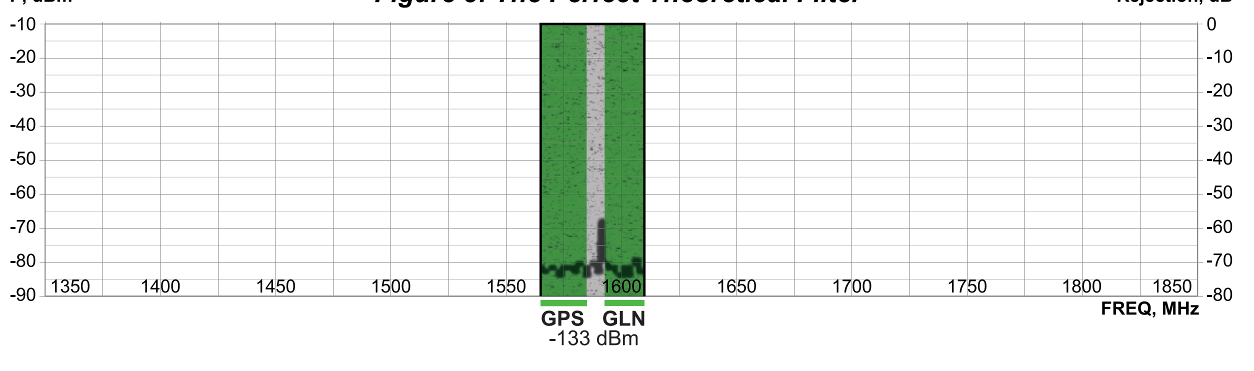


Figure 3, shows a perfect theoretical filter. It allows 100% of GNSS signals to pass from the antenna to the receiver, and it blocks 100% of all radio signals outside the spectrum allotted to GNSS. Such a filter would give us the best possible theoretical signal-to-noise ratio in a receiver and the best possible theoretical receiver performance. This theoretical filter would let in all signals in the GNSS spectrum pass, and completely blocks everything else.

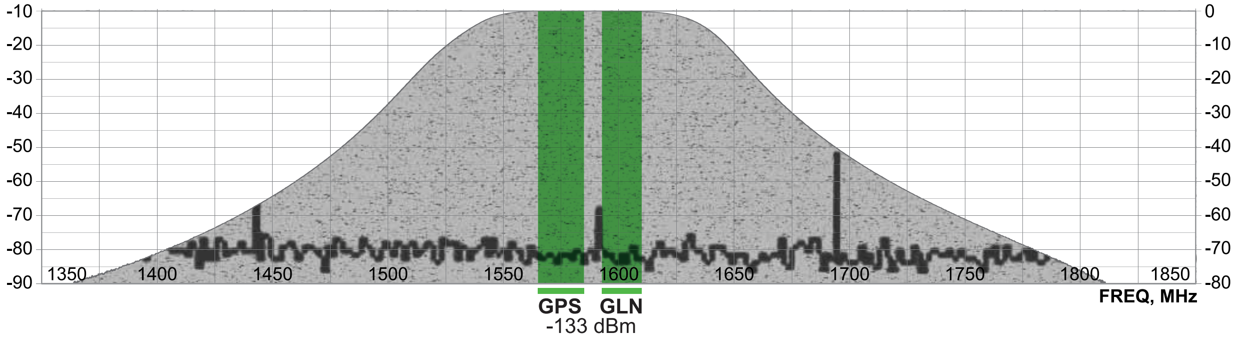
Figure 3: The Perfect Theoretical Filter



Unfortunately, it is not technically possible to build such a perfect filter. Our challenge is to build the best filter that keeps the GNSS signals intact and blocks unwanted signals as much as possible. In other words, make the side slopes, or skirts, of a filter as steep as possible. How difficult it is to build such a filter? How much would it cost?

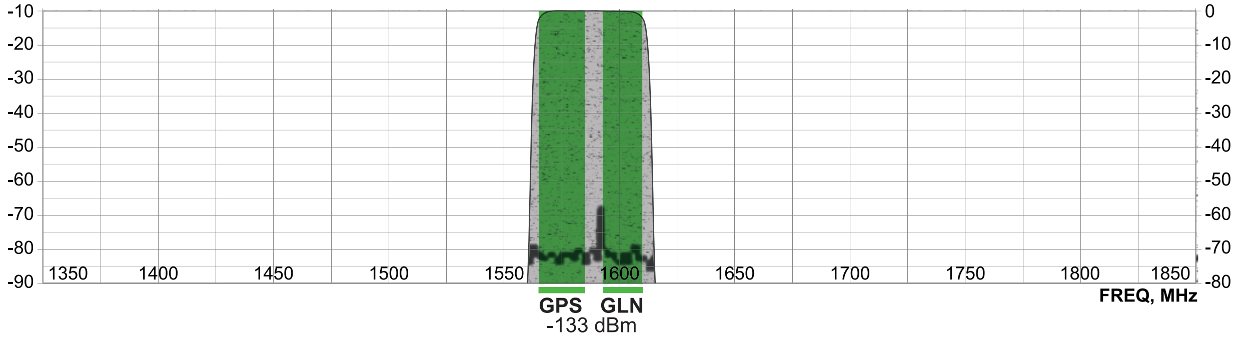
First let us look at the filter that we were using in my own company's GPS receiver products (see **Figure 4**). Those long, gently sloping skirts are not good. Filters with this shape allow a lot of white noise and strong signal spikes into the receiver that a GNSS device doesn't need, and doesn't want (the overall grey area). I knew we could do better, and this is why I set out to find a solution that filters out as much as possible.

Figure 4: A Typical GPS Filter with Little Protection



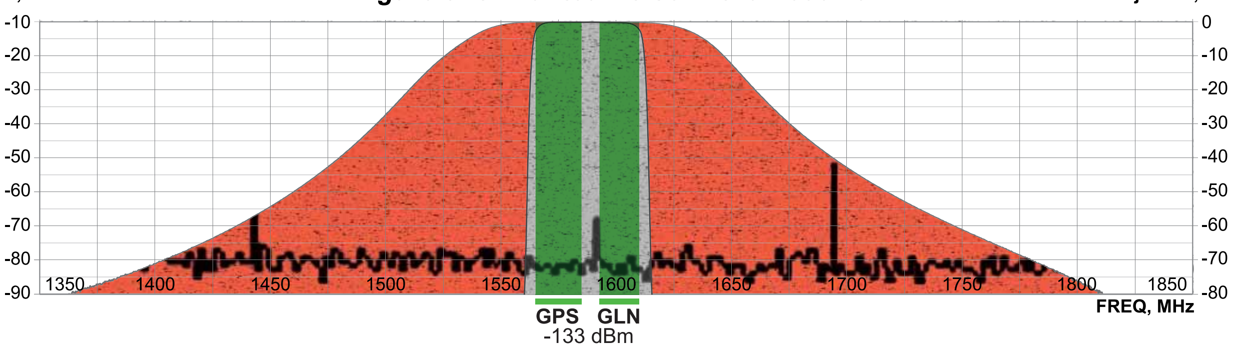
As an innovator, I always want to improve our filter designs and enhance overall performance. **Figure 5** shows the performance curve and shape of a filter that we built and tested that met these criteria. And as you see below, the skirts on this filter are nearly vertical, indicating that we were able to block out almost all the noise. In technical terms, the slope of the filter on each side is about 10dB per MHz. In the future we may be able to do even better, but today, I think this the state-of-the-art design. To my delight, there is considerable benefit to this new filter because it is simpler, it performs better and it costs less than our old filter design.

Figure 5: New Javad GNSS Filters, Enhanced Performance



The performance difference between the old filter of **Figure 4** and new filter of **Figure 5** is enormous. The red section in **Figure 6**, below, illustrates the extra noise and undesirable signals that our old filter was allowing to pass from the antenna into the receiver. All of that extra noise degrades the performance of GNSS receivers.

Figure 6: Unwanted Noise in the Receiver



To think in laymen's terms about such performance degradation, consider having a conversation with a friend in a quiet room. Now consider trying to have the same conversation in a crowded restaurant with waiters shouting to each other (noise spikes) and all the restaurant customers talking loudly to overcome all the background noise. All that extra noise makes it a lot harder to understand what your friend is trying to say to you. The same is true for radio receivers: the more background noise they hear, the harder it is for them to detect and understand the signal that they are supposed to be listening to.

As **Figure 6** shows, we had a lot of extra noise coming into our GNSS receivers. Note again that we are not discussing LightSquared here. Our focus is to improve the performance of GNSS receivers by eliminating as much noise as possible from the red zone – whether coming from a LightSquared transmitter or any other source.

If you are out in the countryside in an electronically quiet environment, you may see only small amount of improvement with our new filter, but in cities, where there are lots of other transmitters, the improvement will be significant. With the new filter, you probably will be able to get a Real Time Kinematic[2] (RTK) solution faster and with greater accuracy. With the old, broad-skirted filter, you will need to stay longer in one position to get a position fix, and your solution may not be as accurate. Indeed, your receiver might stop functioning completely if there's too much radio noise. All practicing surveyors will say that there have been times when their receivers were not functioning properly. They usually blame it on foliage, rain, and other physical environmental conditions, when the real problem often is a noisy radio spectrum environment that does not allow enough margin for operation under foliage and where GNSS signal reception is weaker.

In scientific terms, the filter of **Figure 4** can allow enough noise to get into the receiver to create the equivalent of several dB of additional "noise figure"[3]. To put this in perspective, a good receiver has a noise figure of less than 2 dB. Most engineers would agree that an effective noise figure of more than 3 dB means poor receiver performance. Allowing extra noise into the receiver can make the effective noise figure much more than 3 dB.

It's important to distinguish between "noise figure" and "signal-to-noise" ratios that are determined at the end of the signal processing. Even 1 dB of additional "noise figure" will degrade performance, but several dB change in signal to noise ratio might not be noticeable at all in a GNSS receiver. Please note that the discussion so far has nothing to do with LightSquared. Everything I've outlined thus is meant to improve receiver design overall.

[2]RTK devices are high-precision receivers that use information from terrestrial transmitters to provide additional information, allowing more precise positional solutions.

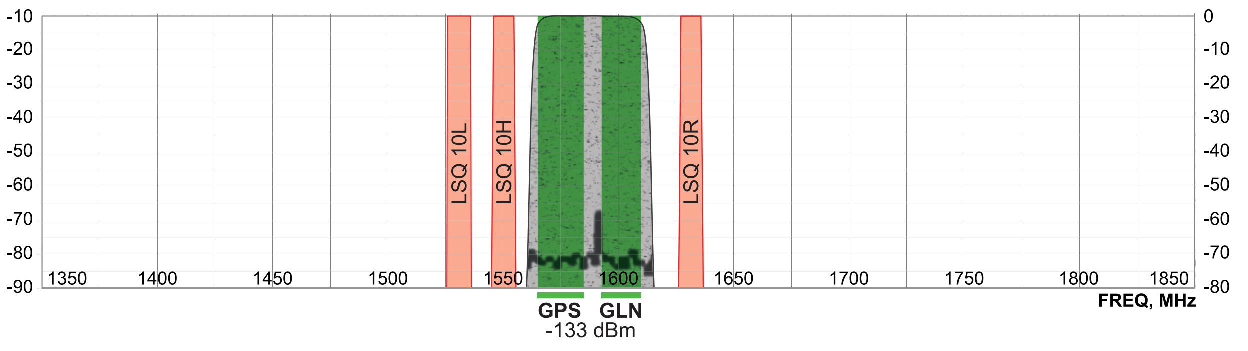
[3]Noise figure is defined as the difference (in decibels) between a theoretically perfect receiver that does not generate any noise internally, and a real-world receiver.

Better Filters Provide Multiple Benefits

I think this discussion shows that other GNSS manufacturers are not showing a desire to innovate and improve their designs. Either they don't want to block out noise, or they don't have the technical competency to do so. The filter in **Figure 5** is much better than the one in **Figure 4** because it provides superior performance for GNSS receivers, with or without LightSquared. If they thought they couldn't build such filters without negative side effects, they were wrong – we have demonstrated that it can be done.

If we build better filters and better GNSS receivers, both general purpose users and high-precision users of GNSS will get improved results. In addition, the **Figure 5** filter will protect the receiver from hearing LightSquared signals. This is shown in **Figure 7**, below. The GPS and GLONASS signals are shown in green. Our new steep-skirt filter is shown in grey, and the LightSquared signals are pink. Note that this new filter completely blocks out the LightSquared signals without reducing the signal strength of GNSS signals.

Figure 7: Improved Filter Solves Interference Problem with LightSquared



This improved filter design should make it clear that LightSquared can coexist with GNSS. Once we understand that, we can also understand that high-precision GNSS receivers can benefit from LightSquared. We can use LightSquared for RTK communication (the land-based signals that augment signals from GPS satellites and provide more precise positional data). We desperately need better RTK communication, and LightSquared's network can provide it.

My desire to innovate filter design was evident in my presentation at the 2011 ESRI conference, where a representative from LightSquared spoke with me on a panel. He was intrigued by the challenge I wanted to tackle offered to support my efforts to build a new and improved filter.

The GPS Community's Response (or Non-Response) to Scientific Facts

Since the ESRI conference, the community's response has been a mix of good, bad, and even ugly. The good part is that our cooperation with LightSquared led to effective and cost-effective solutions to the technical problem. The bad part was that most of the GNSS receiver community stuck fingers in their ears and said, in effect: "I'm not listening! I can't hear you!" The ugly part came in the form of numerous hostile responses I received when I presented my solution at the 2011 PNT[4] meeting, published my findings, and partici

[4]*The National Executive Committee for Space-Based Positioning, Navigation, and Timing (PNT) is a U.S. Government organization established by Presidential directive to advise and coordinate federal departments and agencies on matters concerning the Global Positioning System (GPS) and related systems.*

pated in the GPS World webinar.

Proving that it was possible to design and build a filter that would improve GNSS receiver performance, and do away with the possibility of interference from LightSquared, made me a villain to the status quo. But I ignored their hostility because my objective is to build better receivers, not please the establishment.

I soon took the designs out of the theoretical realm and successfully built a number of prototypes to test in the laboratory and in the field. The results were successful, and within just a few months from the point when I decided to tackle this problem, we were in full production – not only were my new devices more accurate because they filtered out unnecessary noise, they were cheaper to produce and they were compatible with LightSquared.

The PNT Advisory Board's letter to the FCC Chairman on August 3, 2011 blamed LightSquared for the interference and asserted that the only solution was to shut down the company. Rather than innovate and develop a technical solution to the interference problem, those on the PNT Advisory Board, several of whom represent the major GPS companies with a financial interest in the outcome of this debate, chose to use their political might.

The Sound of Silence

I chose to let the science inform my opinion. We developed a theoretical solution, created an experiment to test it, and proved that the theory was correct. The last step in the scientific process is that experimental results must be replicable. To assist others in replicating my findings, I took 40 units of the new system to the November PNT Advisory Board Meeting and offered our new filter design to those who wished to test them. Some people took up my offer, but nobody has come out in public and announced the results of their own tests. Did anyone conduct any tests? If so, what were the results?

All I heard was silence! I have to assume that any tests that were actually conducted in fact replicated our results. If the new filters didn't work, opponents of LightSquared would have been shouting their test results from the rooftops.

The reaction from many of my industry peers to my scientific analysis was decidedly unscientific. My pure technical findings were tagged as hostile, harsh, disrespectful, political, self-serving and betraying. I ask my critics: How in the world could I possibly want to cause harm to GNSS systems that I have worked so hard in the past 30 years to improve? If GNSS system receives any harm, my company and I are among the first to feel the damage!

I'm not a stranger to controversy, so I chose to ignore them. I received similar personal attacks for ten years when I was working on GLONASS. Déjà vu!

Despite my findings that proved the August 3rd letter technically wrong, the PNT did not correct the record, nor did they offer an apology to the FCC chairman for making false claims. In the scientific community, an organization that puts out such blatantly wrong information loses its credibility and goes silent for a while.

So recently, others inside the government created a new smoke screen: low precision (C/A code only) receivers. The government tests reported that 75% of low-precision re ceivers “failed” a compatibility test with LightSquared, but what they neglect to explain is that their definition of “failure” is 1-dB loss in signal-to-noise!

There are two points to note: First, most receivers have up to 20-dB of margin on signal-to-noise and users most likely will not even notice a 1-dB loss. Second, if you take any one of the so called “failed” receivers near many existing transmitting systems (like AM and FM radio and TV towers) you will see that they will lose some dB’s of signal-to-noise or they may completely stop functioning. Should we force all such transmitters off the air? Or better yet, should we demand that GPS receivers that are being used in critical applications have protection against existing systems? I wrote a letter regarding this issue to the FCC Chairman recently outlining my point-of-view on this false rationale.

Next came the issue that LightSquared interferes with avionic systems that warn pilots about approaching terrain and mountains. This was tested in a laboratory. In addition to all I mentioned earlier, the test also ignored that LightSquared towers are aimed six degrees below the horizon and transmit 20-dB (100 times) less power in directions above the horizon. Those conducting the testing and analysis of the data clearly chose to ignore some facts.

It Would Be Funny If It Weren’t So Tragic

The story does not end here. According to the official test results, 300 million inexpensive GPS receivers built into cellular telephones are not affected by LightSquared. However, the very expensive encrypted military GPS receivers that are supposed to be battle hardened are affected!

Why is no one asking the Pentagon why they procured equipment that’s vulnerable to wireless signals of all things?

One may argue that the reason military receivers did worse than cell phones is that military receivers use wide band P-code. This is exactly my point; the military receivers which use wide band un-encrypted P-code for the main purpose of getting better protection against interferences, end up performing worse than even a cell phone in the presence of interference. This also applies to the FAA. Everyone in Washington ignores these facts!

This technical matter has a lot of lawyers, lobbyists and spin doctors involved, but it’s the engineers who have the ability to solve this problem.

No matter what happens to LightSquared, I am determined to build a better filter system for our GNSS receivers and offer better products to surveyors worldwide, and if we can accomplish this while facilitating a better RTK network, all the more reason.

I would like to invite engineers who want to roll up their sleeves and find solutions and discuss technical details to join me and several of my peers on Tuesday, January 17, 2012 in my San Jose facility. Please RSVP to javad@javad.com.

Javad Ashjaee