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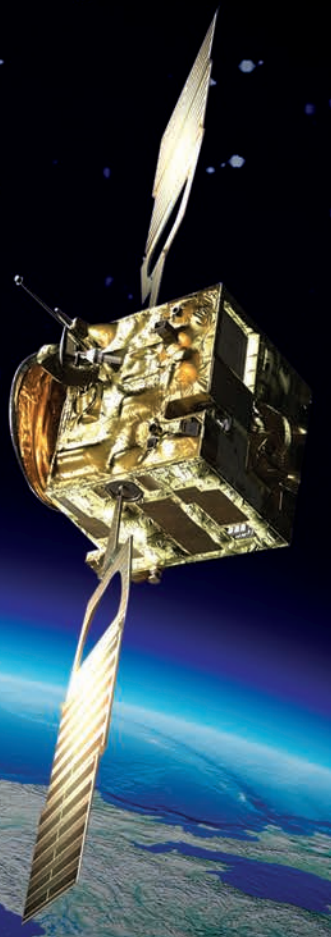


How GPS and GLONASS Got Together — and Other Recent Events

It All Began in 1989

How GPS and GLONASS Got Together — and Other Recent Events

The recent broadcast of the first CDMA signal from the new GLONASS-K satellite culminates a long series of events that began in 1989. A key participant gives a first-hand account of the history of many meetings, formal and informal, that created true interoperability between the two major satellite systems, giving users a modern GNSS in action.

Javad Ashjaee

October 18, 1989, the Queen Elizabeth Auditorium in London, around 8:30 am. Unknown to me, two 60-minute periods were about to imprint themselves indelibly on my memory.

I walked up the stairs to the exhibition booth of my company, Ashtech, at The Royal Institute of Navigation conference. My good friend, the late Ann Beatty, met me and asked, "Any news from home?"

I thought it was just a casual customary question, and replied: "Thanks, all OK." She had a strange look on her face. She continued: "Are all your family really OK?" I replied again: "Thanks, all good." She then realized that I had no clue about the cataclysmic event that had hit the San Francisco Bay area. She abruptly said, "Don't you know? The big one came! The big earthquake hit San Francisco!"

Californians know the rumors that when The Big One comes, Nevada will have ocean frontage. Now she was telling me that The Big One came! I rushed to the phone, and the recorded AT&T message said, "All lines to your area are out of service." It took me another hour to find out that this was not yet The Big One, and that my family was safe. I

▲ **FIRST MOSCOW MEETING** The late Dr. Vadim Alexandrovich Salichev, a GLONASS program scientist, is on the far right, next to Dr. Ivanov. On the far left, next to me, sits Dr. Yury Nikolayevich Korolev, GLONASS senior scientist.

▲ **DR. NIKOLAY YEMELIANOVICH IVANOV** signs the protocol of our cooperation to combine GPS and GLONASS.

▲ **IN THE EVENING** after the first meeting they took me to a restaurant for dinner. This photo with Dr. Ivanov, director of the GLONASS program, shows how fast our friendship grew.

will never forget these 60 minutes of my life. Never!

Nor will I ever forget the events of the next 60 minutes.

After the stress had settled a bit, a delegation from the Russian Space Agency visited our booth. First they expressed their sympathy regarding the earthquake. Then we discussed GPS technology and its similarities with GLONASS. Both systems were fairly new then, although GPS had started first, with a Block I launch in 1978, followed by GLONASS with a launch in 1982. At the time we met in London, GPS was flying 12 satellites, and GLONASS also had 12 in orbit.

The Russian delegation visited all GPS manufacturers' booths in the exhibition hall and then gathered in the coffee area for their private discussions. A few hours before the conference closed, they returned to our booth and said, "We want to combine GPS and GLONASS, and you are our first choice." Simply put, I was fascinated and excited.

After working out visa and travel details, four months later I arrived in Moscow in the cold days of February 1990. It was still the Soviet Union.

I had grown up in Iran where the U.S.S.R. was our neighbor to the north. Remembering the global political landscape of my childhood days, I felt both fascination and fear as my airplane landed at Moscow airport.

Upon meeting the people who greeted me at the airport, my fears disappeared, and my fascination grew stronger.

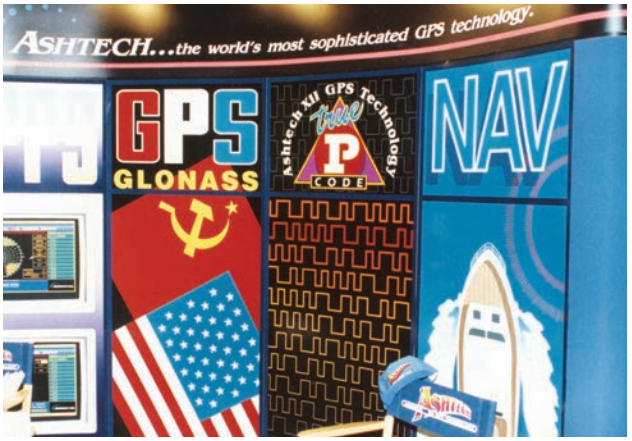
Our first formal meeting took place in the Institute of Space Device Engineering (ISDE), a division of the Russian Space Agency that was responsible for the GLONASS program. The **OPENING PHOTO** shows me with the late Dr. Nikolay Yemelianovich Ivanov, director of the GLONASS program, at that first meeting.

I want to focus a bit on the GLONASS team and applaud them for their efforts. What makes the GLONASS team special is that they worked under much harder political

▲ **SECOND MOSCOW MEETING.** On the right side are Dr. Ivanov and his team. On the left side, the second person from the left is the late Dr. Stanislav Ulianovich Sila-Navitsky. Behind me is my then-vice president Jon Ladd and two of our best engineers, Roger Helkey and Robert Lorenz. Years later Jon joined NovAtel as its CEO and did a great job in growing NovAtel.

▲ **REAL DINNER** in General Gusev's Paris hotel room. General Gusev is on the right. Facing him is Dr. Ivanov. With his back to the camera is Dr. Salichev, and facing the camera are Stas and Bob Lorenz. General Gusev still has a consulting role with ISDE. GLONASS misses the three on the left: Stas, Ivanov, and Salichev, who have all passed away.

▲ **THIS IS HOW IT'S DONE.** Satnav discussion in General Gusev's Paris hotel room. Ivanov is pouring, Stas is laughing.



▲ **ION 1990 ASHTECH BOOTH** displaying U.S.S.R. and American flags.

▲ **INTERVIEW WITH RUSSIAN TV** upon announcement of our combined GPS and GLONASS products in Moscow. In back on the left is Dr. Viktor Stepanovich Kislov, now deputy executive head, Russian Cadastre and Cartography Registration; next to him, his deputy Dr. Boris Alexandrovich Altshuller, now director of Land Survey of Russia.

and financial conditions than the GPS or Galileo teams. But still they were able to make the project successful. The Soviet Union and later Russia went through huge political, economic, social, and geographical revolutions, but the GLONASS team managed to keep the satellite navigation program alive and successful.

Galileo's management, while enjoying much more stability and financial luxury, can certainly appreciate and understand the significance of what the GLONASS team accomplished. Galileo also benefitted from the European integration of 27 countries, while the Soviet Union disintegrated into 15 separate nations.

Despite all their heroic work, individuals on the GLONASS team have received almost no international recognition. At home they went unnoticed, due to their political situations. For example, the highest international recognition that Dr. Ivanov received was that he became a member of the *GPS World* Advisory Board, which I facilitated. In this article, I want to salute some members that I know and at least keep their names and photos recorded in the *GPS World* archives.

In the first meeting, everyone recognized and emphasized the great potential of combining GPS and GLONASS for a variety of applications. I became more assured of the deep desires of my hosts to make this happen. They had prepared detailed charts and plans, especially for high-precision applications. They also gave me the GLONASS Interface

Control Document (ICD) for the first time.

We signed a cooperation protocol and agreed to explore technical details in our next meeting, which occurred a few months later. There I began to know Dr. Stanislav "Stas" Ulianovich Sila-Navitsky, at that time the chief scientist of Dr. Ivanov's team. Later he became my vice president in three companies that I founded. He also became my best friend of 19 years, before he passed away on May 7, 2010.

We had several meetings in Moscow and one in Paris in the headquarters of our partner SAGEM.

I have wonderful memories of all the meetings. One meeting in Paris included General Leonid Ivanovich Gusev, the head of ISDE. One evening Stas called my hotel room and asked me to cancel our dinner at a famous French restaurant and instead join them for a "real dinner." Apparently General Gusev was tired of French food! The real dinner took place in the General's hotel room, and the menu consisted of dark Russian bread, Russian kielbasa sausage, Russian seledka herring, and an abundance of Russian vodka.

Our first announcement of combining GPS and GLONASS was published in *GPS World* magazine, in only its second issue, March/April 1990. That year we had a poster banner in our Institute of Navigation exhibition, showing the American flag and the Soviet flag (hammer and sickle) next to each other. My very good friend, Colonel Gaylord Green, the second director of the GPS Joint Program Office, refused to have his picture taken with me in front of that banner. Instead, we stood over to another side of the booth for his photo.

A few months after the Paris meeting, the political process known as perestroika began and caused the Soviet Union to end. Life became extremely difficult for Russians.

I called Stas to discuss the situation. We concluded that we had no choice but to continue the plan on our own if we wanted to combine GPS and

GLOBAL VIEW

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Pioneer/Trimble vehicle tracking system ready for Japan

Sony prepares GPS handheld receiver for market

Permanent GPS network established

Ion GPS-90 calls for abstracts for September event

Ashtech Signs with Soviet Agency to Build GPS/GLONASS Receiver

In what may be the first U.S.-Soviet commercial joint venture in satellite positioning technology, Ashtech, Inc., has signed an agreement with the Institute of Space Device Engineering (ISDE) to develop a combined GPS/GLONASS receiver. GLONASS is the USSR's counterpart of the global positioning system and is expected to have 24 agency equivalent to the United States' National Aeronautics and Space Administration (NASA).

The arrangement will take advantage of Ashtech's expertise in GPS technology to build a portable, survey-accuracy receiver for civil applications, according to Ashtech's President Javad Ashjaee, Ph.D. "Designing a combined GPS/GLONASS receiver poses a very interesting scientific challenge," says Ashjaee, who spent two days in final negotiations with a team of ISDE representatives ranging from programmers and engineers to top officials of the agency. Receivers will be marketed both within the Soviet Union and elsewhere.

Key technical elements of the project include integrating the different timing and geodetic coordinate datums used by the two satellite systems as well as the different L-band carrier frequencies occupied by the GPS and GLONASS signals. Unlike the global positioning system, GLONASS satellites do not all transmit on the same carrier frequency, but instead each satellite has its own carrier frequency within the allocated 1597–1617 megahertz band width.

ГЛОНАСС

ASHTECH INC.

Ashjaee emphasizes that the each. "Both parties, both sides have expertise that can help each other," Ashjaee says. A key advantage of the joint venture is that Ashtech scientists will no longer have to decipher the navigational data structure transmitted by GLONASS satellites, or guess about unknown elements of the GLONASS system. "They will also let us know about any changes in the data structure in the future," Ashjaee adds. "The product in the field will have the support of both countries."

Ashjaee noted that it was his first trip to Moscow and his first visit with Soviet scientists and officials. "I found them to be very intelligent people with a good theoretical background, very pleasant people to deal with," he says. "They are team players and willing to honestly work with the Western world, following the changes taking place in their country. They implied that there was a selection process in which they looked at various companies and technology, and I was very proud that they consider Ashtech to have the best GPS technology."

Other organizations have also indicated an interest in a combined GPS/GLONASS receiver. The U.S. Federal Aviation Administration has contracted with Lincoln Laboratory at the Massachusetts Institute of Technology to develop a prototype of a combined receiver, with field testing expected to begin this summer. Magnavox also has been working on a GPS/GLONASS receiver for the past year or so.

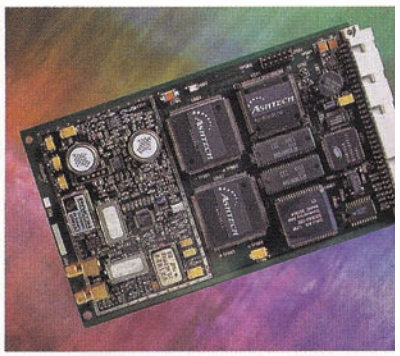
ANNOUNCEMENT of the agreement to build a combined GPS/GLONASS receiver, in the second issue of *GPS World*, March/April 1990.

GLONASS. I went back to Moscow several times, and in February 1992 officially opened the Moscow office of Ashtech. This office is still operational in Moscow with about 10 percent of the original team. It is now in the process of being purchased by Trimble Navigation. What a turn of events!

In 1996 we introduced the first combined GPS and GLONASS receiver; the product announcement appeared in *GPS World,* July 1996.

Back home in the United States, the situation was different. Supporting GLONASS was an unpatriotic act. The most prominent figures of GPS teased me for wasting my time with GLONASS. The news favored their arguments: the Russian economy was going downhill. In September 1998, the Russian ruble collapsed more than 300 percent within a week. Banks closed. Even Coca Cola was not able to pay its employees in Russia because of bank closures. Many western companies left Russia. During that period, I intentionally stayed longer times in Moscow and managed to pay our employees without a day of delay. Furthermore, a more than three-fold rate change in favor of the dollar made our employees relatively rich, because their salaries were based on the U.S. dollar.

I remained confident that GLONASS would succeed because I had seen the enthusiasm and dedication of GLONASS management



GPS/GLONASS receiver ▲
A combined GPS/GLONASS receiver from Ashtech provides increased satellite coverage with at least 11 satellites (of 48) visible at all times — making GG24 ideal for operating in often obstructed environments (such as cities with tall buildings, mountainous areas, and under tree cover). According to the company, position accuracy typically ranges from 7 to 15 meters without differential correction techniques and as accurate as 40 centimeters using standard RTCM input for accepting real-time correction data. GG24 requires only one antenna for both signals and has a 2-second reacquisition time. **Ashtech,** Sunnyvale, California, USA.

▲ **FIRST GPS/GLONASS RECEIVER,** from the pages of *GPS World*, July 1996.

and engineers.

My Ashtech partners wanted to take the company public to recoup their investments. They thought Wall Street would negatively view GLONASS and the Russian connection. So my aspiration did not match theirs, and I started Javad Positioning System (JPS) in 1996. About 90 percent of the staff engineers followed me to JPS.

One of John Scully's vice presidents did to Ashtech what Scully did to Apple. Meanwhile JPS became very successful, as Apple did when Steve Jobs returned.

Subsequent to another event and termination of some obligations and commitments, I started JAVAD GNSS in June 2007. Almost all of the key people followed me again. Our current team has a history of working together for close to 20 years.

In JAVAD GNSS we raised the bar of GPS/GLONASS integration to a higher level and focused in two new directions. The first was to eliminate the problem of GLONASS interchannel biases, which is inherent to the GLONASS frequency-division multiple access (FDMA) signal structure. The second was to support the opinion of GLONASS engineers who were pushing for a new code-division multiple access (CDMA) signal for GLONASS, similar to the GPS signal.

We resolved the GLONASS interchannel biases issue around 2009 and announced, "Our GLONASS is as good as GPS."

On the second front, we worked with the top managements of ISDE and the Information Analysis Center (IAC) of the Russian Space Center to demonstrate the advantages of CDMA for high-precision applications.

Some years ago, Stas had confided in me that the issue of CDMA was nothing new, and had been extensively deliberated at all levels of various GLONASS organizations during the early design phase of the system. The result of all these discussions was that engineers and technical people favored CDMA, but the higher management, mostly influenced by the military organizations, held out for FDMA. The reason for favoring FDMA is still a secret, though some believe that they just wanted to be different from GPS and did not see much advantage in CDMA. Some also believed FDMA gave better jamming protection.

Of course in those very early days, no one imagined using GPS or GLONASS for high-precision applications, and as such truly there was not much difference between CDMA and FDMA. Much later, the notion of using carrier phase of GPS and GLONASS signals for high-precision applications was discovered, and then the advantages of CDMA became relevant, as Dr. Ivanov also hinted in our first meeting.

After we combined GPS and GLONASS, and as a lot of our worldwide users began comparing the two systems, the issue of CDMA versus FDMA again came up for discussion among the GLONASS authorities.

More recently, since 2007, we had several meetings in the offices of ISDE in Moscow, in IAC in Korolev (the Russian Space City), and several in our JAVAD GNSS office in Moscow. Most importantly, we had several meetings in my Moscow apartment, enhanced by Russian vodka and the best Armenian cognac, courtesy of Sergey Revnivykh, head of IAC. All meetings were open and candid, discussing and demonstrating the advantages of CDMA, in support of the ISDE engineers who were reluctant to express their opinion above certain levels.

I also met with the head of the Russian Space Agency, Dr. Anatoly Nikolayevich Perminov, who personally supported and sponsored me in obtaining an extended Russian residency visa. Let me also express my appreciation for receiving the Medal of Honor from the Russian Cosmonauts Federation, along with the official astronaut watch. I don't understand the reason for receiving a Kalashnikov AK-47 semi-automatic rifle from ISDE for my birthday. I wonder how I can transport it home!

General Anatoly Shilov (deputy director of the Russian Space Center), Dr. Vicheslav Dvorkin (GLONASS deputy general designer), Sergey Revnivykh, Viktor Kosenko (first deputy of chief GLONASS designer) and Sergey Karutin (GLONASS senior scientist) are the new generation of GLONASS leaders who deserve credit for supporting CDMA on GLONASS. Recently, a new GLONASS-K satellite was launched, transmitting an experimental CDMA signal in addition to the legacy signals. Almost immediately, we announced tracking of the new GLONASS-K satellite and its new L3 signal details, hours after it started transmitting. See *GPS World* archives and our website for details of this signal which seems, in all aspects,

as good as GPS.

Another new issue of significant international concern was a new frequency for GLONASS. This issue was more political than technical, and is discussed under the umbrella of interoperability.

In the early days of my frequent travels to Russia, the KGB probably suspected that I was a CIA agent — and the CIA probably suspected that I was a KGB agent! I would not be surprised if both the CIA and KGB monitored every bit of my travels and activities. After some years, the San Francisco airport authorities stopped interrogating me for my activities in Russia any time I came back home. Perhaps because of their deep investigations, I earned the trust and friendship of both sides, and their confidence that I had nothing in mind other than helping to integrate GPS and GLONASS. I was an unofficial member and friend of both U.S. and Russian delegations during the so-called interoperability discussions since 2007, which sometimes touched on the CDMA issue as well.

Some of the most fruitful and friendly discussions between the U.S. and Russian delegations occurred in my apartment in Moscow, after their official meetings. Ken Hodgkins of U.S. State Department; Mike Shaw, director of the National Space-Based Positioning, Navigation, and Timing Coordination Office; David Turner, director of the Center for Space Policy & Strategy; Scott Feairheller of the U.S. Air Force; and Tom Stansell, consultant to the GPS Wing were some of my honored guests.

The new GLONASS frequency discussions are still in progress, and I am proud to host and support both sides the best that I can. Sometimes it is fun to observe that discussions resemble poker games where hands are known to all sides, but players still try to bluff each other! Let's leave it at that for now.

In May of this year, I had a conversation with General Anatoly Shilov, now second-in-command of the Russian Space Agency, reporting to the first deputy of the minister of defense, General Vladimir Popovkin, who recently replaced Dr. Perminov as head of the Russian Space Center. This is an indication of increased attention and support from the Russian government to its GLONASS program. In our conversation, General Shilov was enthusiastic and optimistic that the GLONASS program will move forward faster.

GLONASS has proven to be a real and reliable complement to GPS. If it were not for the failure of the launch of three GLONASS satellites in December 2010, its constellation would be complete and fully, globally operational today. It will happen soon. Sergey Revnivykh estimates that currently the system has 99.8 percent global coverage.

Today, a truly reliable and fast RTK is not possible without combining GPS and GLONASS satellites.

The most recent testimony to the success of GLONASS comes from the long-time GLONASS opponents who once

▲ **STAS HELPING** our cook prepare dinner for my daughter and her friends when they visited Moscow.

▲ **MEDAL OF HONOR** of the Russian Cosmonauts Federation. The certificate reads: "Russian Cosmonauts Federation Medal of honor. According to the decision of the Presidium of Russian Cosmonauts Federation, from January 26, 2009, Javad Ashjaee is awarded this Medal of Honor for participation in the implementation of space projects." This is a unique recognition for a foreigner in Russia.

FDMA and CDMA

Multiple access, a basic concept in data communication, employs several transmitters to send information simultaneously over a single channel. The code-division multiple access (CDMA) approach adopted by GPS in the 1970s (and by Galileo and Compass since then) uses spread-spectrum technology and a special coding scheme, where each transmitter is assigned a separate orthogonal code, to allow several messages to be multiplexed over the same single-frequency physical channel. By contrast, frequency-division multiple access (FDMA), also a spread-spectrum passive ranging technique, divides the channel by frequency. Brad Parkinson stated that "the CDMA modulation used for passive ranging is clearly the most fundamental innovation of GPS" in *GPS World*, July 2010.

▲ **INFORMAL INTEROPERABILITY MEETING** in my Moscow apartment. From left to right: David Sterne, Pentagon GPS team; Glen Gibbons, former editor of *GPS World*; Col. Mark Crews, GPS Wing representative (he signed the CDMA memorandum with Russia in 2007); Dr. Stanislav "Stas" Ulianovich Sila-Navitsky of JAVAD GNSS; Mike Shaw, then director of the U.S. PNT Coordinating Office; myself; Sergey Revnivykh; Ken Hodgkins, U.S. State Department; Ekaterina Andrushak, Russian Space Center international relations; Dr. Rudolph Bakitko, senior GLONASS designer; and Scott Feairheller of the U.S. Air Force.

criticized me for supporting the system. Recently they had to pay a lot of money to acquire the first company that I founded in Moscow, which they believed would never survive.

This year at JAVAD GNSS, I and most of my original employees and GLONASS designers are celebrating our 20th year in Russia, and we are working harder to make the integration of GPS and GLONASS even better.

On May 7, 2010, Stas lost to leukemia. He was not present to witness the successful introduction of our TRIUMPH-VS receivers. My refrigerators in Moscow are full of medicines that he brought for me any time I had a little cold. I miss him a lot, and our team is dedicated to following the path that Stas loved so much.

I want to briefly summarize the current status and the future of GPS and GLONASS from the users' point of view.

GLONASS now has 24 satellites transmitting FDMA signals in two frequency bands. The failure in the last launch to deploy three more satellites delayed completion of the constellation to the end of 2011. The good thing about GLONASS is that both of its L1 and L2 signals are not encrypted and give better data than GPS P1 and P2 that are encrypted.

GLONASS is considering a plan to add CDMA signals to all satellites and not suffer from inter-channel biases. But it will take about 10 years for this plan to become complete for public use, even if the plan is approved and followed. At JAVAD GNSS, we have already mitigated the effect of GLONASS inter-channel biases to the accuracy of better than 0.2 millimeters. We made GLONASS FDMA the same as GPS CDMA by adding some innovations (patent pending) and enhanced algorithms.

The GPS plan is to add a third frequency signal (called L5) and add an unencrypted signal in L2. But it will take several years to have enough new satellites transmitting these new signals to make them usable for daily work.

In the near term, we have two complete systems, consisting of about 30 GPS and 27 GLONASS satellites. The current non-encrypted GLONASS signals give it an edge over the current GPS encrypted signals, given the fact that we have mitigated the GLONASS FDMA inter-channel biases.

GLONASS is also enhancing its control segment to better monitor GLONASS satellites and improve the system's clock and orbit parameters. Most of these errors are cancelled in differential and high-precision applications anyway.

Existence of two complete and free systems, GPS and GLONASS, will place some doubt on the future of Galileo, as it will be extremely difficult for Galileo to hope to collect money from users to fund itself. The addition of Galileo, as a third system, will not really add much benefit for users anyway. The only push for deploying Galileo must come from some European military organizations to support their specific interest.

I have been extremely fortunate also to have had the opportunity to work on GPS from its early days, co-pioneering high-precision applications at Trimble Navigation. I owe a lot to Charlie Trimble, who helped me to lift myself up when I sought refuge in the United States in 1981. He taught me GPS as well as dedication in business. I also benefitted from Sunday meetings with Dr. Bradford Parkinson, the first program director of GPS, who was and still is a board member of Trimble Navigation. I am curious to find out how Brad, as a board member, voted in the recent matter of the purchase of Ashtech. Since leaving Trimble, my innovative products at Ashtech, JPS, and JAVAD GNSS have been well documented through the years in *GPS World*.

My emphasis on GLONASS in this memoir is only to record some histories and recognize GLONASS and some of its pioneers who were often overlooked. GPS is already a well-known, well-established system and is the backbone of GNSS.

As a final note, let me add that our current JAVAD GNSS products have the option of tracking all current and future signals of GPS, GLONASS, QZSS, and Galileo. Yes, Galileo too!