IT’S BA-A-A-CK!

Ligado Wins FCC Approval to Operate Near GNSS Band

Widespread congressional and industry opposition has emerged following the Federal Communications Commission (FCC) approval of a controversial plan by Ligado Networks to establish a terrestrial broadband network in frequencies adjacent to the most widely used GPS band.

The unanimous FCC decision, announced April 20, reversed a previous decision in 2011 that denied a similar proposal from Reston, Virginia-based LightSquared until the risk of harmful interference to GPS could be removed. That decision followed an extensive test campaign in 2011 overseen by LightSquared and the GPS industry that demonstrated extensive interference with GPS and other GNSS equipment operating in the L1 band centered at 1575.42 MHz.

Many ION members took part in conducting those tests — live over-the-air, in anechoic chambers, and simulated — that showed widespread interference to GPS receivers by transmissions at both upper and lower bands in the 1526–1559 MHz spectrum where the Ligado wants to operate.

In February 2012, the FCC moved to vacate LightSquared’s request based on the conclusion of the National Telecommunications and Information Administration (NTIA) that no practical way to mitigate potential GPS interference existed. With the backing of private investment groups that obtained LightSquared’s assets following the

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COVID-19 Continues to Impact ION

We have all felt the effects of what has become part of our shared international experience with COVID-19. During the pandemic, ION has continued to modify our methods of providing services to our members. When necessary, our programs have evolved and delivery methods have been modified in what has become a highly fluid and changing environment. Like many other organizations, the ION Executive Committee has "Zoom’ed" together on multiple occasions to propose changes based on our rapidly evolving everyday reality, always with our members’ interests in mind.

ION GNSS+ 2020 Virtual Option, FREE for First-Time Registrants

Recognizing that some won’t be able to attend this year’s ION GNSS+ conference and exhibition due to travel and other restrictions, the Institute of Navigation is excited to offer an ION GNSS+ 2020 virtual option with the goal of increasing global accessibility to everyone who wants to participate.

The virtual registration option will include a combination of live-streamed sessions and audio-recorded presentations uploaded with slides to the conference website that virtual attendees will be able to view on demand. Virtual attendees will also be invited to participate in a moderated Q&A.

ION’s goal with the new virtual platform is to provide the ION and GNSS community with access to the latest GNSS developments and premium content through an innovative and timely online experience. And, as part of this objective, ION is providing virtual meeting attendance FREE for many first-time ION GNSS+ attendees.

View ION Webinars

ION has hosted three webinars of NAVIGATION papers this past season by featuring authors Dr. Jordan Larson, Dr. André Hauschild, and Dr. Santiago Perea. I would like to thank these authors for taking the time to provide detailed instruction of their excellent work. The full webinars are available for viewing on the ION website at <https://www.ion.org/publications/webinars.cfm>.

An article on page 21 describes these webinars in greater details as well as how to sign up for news about future webinars.

Further, ION has continued to maintain our editorial calendar. There will not be disruptions to the printing and distribution of NAVIGATION, Journal of the Institute of Navigation, that we had previously anticipated.

ION Launches an Online Job Board

In keeping with our core mission of advancing positioning, navigation, and

The Institute of Navigation is excited to offer an ION GNSS+ 2020 virtual option with the goal of increasing global accessibility.
introducing the NEW
ION ONLINE JOB BOARD

A Resource for Recruiting Qualified PNT Professionals

Looking for talent? Looking for a new career opportunity?

Visit the ION Online Job Board
ion.org/job-board
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company's bankruptcy, Ligado Networks began in 2015 to reassert a modified version of the plan to convert former satellite communications frequencies into a terrestrial network that could support an emerging 5G wireless telephony market and Internet of Things applications.

Ligado several years ago proposed creating a 23 MHz buffer zone or “guard band” between Ligado and GPS frequencies and cutting the Ligado base station power to 9.8 dBW. These measures were taken into account during a new round of testing by the Department of Transportation (DoT) in 2016. That testing showed Ligado’s revised plan still posed an interference risk to GPS receivers.

Key to the agency’s April ruling was the FCC’s announcement that it would abandon a long-established criterion for measuring interference and adopt the “harmful interference” standard advocated by Ligado Networks. The long-accepted interference standard called for no more than one-decibel degradation in the power density ratio in GNSS receivers.

“Under this [newly adopted] standard interference must be addressed only once it’s caused a receiver to malfunction and the issue has been reported,” says Dee Ann Divis, Washington columnist for Inside GNSS magazine. “That puts the onus on the users to understand and report degraded or lost service — but there is no clear plan on where transmitters will be and it is unclear what impact the Ligado handsets might have. There is also no plan to tell commercial users or the general public about the change.”

The FCC required Ligado to agree to several conditions to gain approval for the proposal:
- place its nationwide terrestrial network in bands farther away from the GPS band
- mitigate interference by reducing power levels at its base stations to 99.3 percent less than proposed in its 2015 application
- create a guard band greater than 20 megahertz between its terrestrial service and the GPS band, and guard bands between its terrestrial service and other users
- report base stations’ locations and mitigate any reports of interference.

Opposition Emerges

The regulatory turnaround prompted numerous public and private initiatives to block the FCC’s action.

At its July 1 meeting, the National Space-Based Positioning, Navigation, and Timing Advisory Board — a federal interagency group providing oversight to GPS-related policy and practice — endorsed a report from its first vice-chair Brad Parkinson, that the “FCC has made a grave error in authorizing a high-power, terrestrial communication-network in the mobile satellite service (MSS) radio spectrum adjacent to GPS.”

Parkinson argued that “For [the] benefit of the US, as a whole, this order should be immediately rescinded.”

The GPS Innovation Alliance (GPSIA), whose members include GNSS receiver manufacturers, also expressed deep disappointment that the FCC appears to have ignored “the well-documented views of the expert agencies charged with preserving the integrity of GPS, specifically on the critical issue of what constitutes harmful interference to users of Global Navigation Satellite Systems (GNSS),” said J. David Grossman, GPSIA’s executive director.

Testifying at a May 6 Senate Armed Services Committee hearing, Department of Defense (DoD) officials said they were “surprised” and “completely caught off guard” by the commission’s order. The agency had circulated a “draft” order approving the Ligado plan on April 16, four days before announcing its final approval of it.

On May 8, 23 members of the U.S. House Armed Services Committee wrote to the FCC commissioners expressing their “deep concern” over the agency’s decision. “The national security community was unanimous in the judgement that approval of the use of certain portions of the L band spectrum could pose an unacceptable risk to the use of the Global Positioning System (GPS) in the United States,” the House members wrote.

On May 15, a bipartisan group of 32 U.S. senators urged the FCC to reconsider action, saying it could pose severe risks to military operations. On June 23, five associations representing thousands of companies and millions of American GPS users launched a new organization, the Keep GPS Working Coalition, to protect GPS from potential interference from LightSquared’s system.

The Senate Armed Services Committee approved its version of the Fiscal Year 2021 National Defense Authorization Act by a vote of 25–2 following three days of closed hearings, the committee announced June 11. The bill includes language addressing FCC’s Ligado order, including criticism of the FCC’s “misguided decision to approve Ligado Networks’ request for bandwidth for a terrestrial-based cellular network, that put critical GPS signals at risk.”

The committee’s action would prohibit the use of Department of Defense (DoD) funds to comply with the FCC order on Ligado until the secretary of defense submits an estimate of the costs associated with the resulting GPS inter-
The bill also directs the defense secretary to commission an independent study from the National Academies of Science and Engineering on Ligado’s and DoD’s approaches to testing. Founding members of the Keep GPS Working Coalition include the Association of Equipment Manufacturers (AEM), the American Farm Bureau Federation (AFBF), the American Road & Transportation Builders Association (ARTBA), the Aircraft Owners & Pilots Association (AOPA) and the Boat Owners Association of The United States (Boat U.S.).

“The FCC’s decision threatens GPS reliability for countless consumers, farmers, ranchers, pilots, boat owners, surveyors, construction companies and other private GPS users who will be forced to suffer interference to their GPS devices or to pay to replace them,” the coalition asserted in a press release. “The FCC admits in its order that there are cases where both government and private GPS receivers — including those that power aviation, agriculture and other key industries — will suffer harmful interference, but failed to provide a technically feasible and adequate remediation solution for consumer and business end users.”

**Legislative Action**

As its first action, the Keep GPS Working Coalition endorsed the Recognizing and Ensuring Taxpayer Access to the Infrastructure Necessary (RETAI) for GPS and Satellite Communications Act authored by U.S. Senator Jim Inhofe (R-Oklahoma) and Jack Reed (D-Rhode Island). Among the measures that would be mandated by the legislation are the following:

- Requires Ligado to satisfy additional conditions to the Federal Communications Commission prior to the FCC’s Ligado Order being effective.
- Requires a licensee to upgrade, repair, or replace impacted GPS and satellite receivers. These costs can include the modification, repair or replacement of equipment, spares, associated ancillary equipment, software, facilities, operating manuals, training, or compliance with regulations.
- Lists the costs incurred by a federal agency that must be reimbursed by the licensee.
- Lists the costs incurred by a person or other private sector entity that must be reimbursed by the licensee.
- Requires reimbursable expenses owed are retained by the holder of the licensee holder.
- Ensures the licensee is able to reimburse federal agencies directly.

**The Pushback**

The FCC and Trump administration leaders, including U.S. Attorney General William Barr and Secretary of State Mike Pompeo, have indicated their continuing support for Ligado’s plan. Pompeo had urged FCC approval, saying quick action by the agency is “vital to our national security and will help ensure that the United States is the global leader in advanced technologies.” Barr said that FCC approval “is essential if we are to keep our economic and technological leadership and avoid forfeiting it to Communist China.”

The FCC also pushed back against congressional critics. In a May 26 letter to Adam Smith chairman of the House Committee on Armed Services, FCC
Chairman Ajit Pai rejected the committee’s concerns.

“Although your letter references the shared use of spectrum, the Commission’s L-band decision does not authorize any spectrum sharing between Ligado and GPS,” Pai wrote. “In fact, spectrum in this band has been licensed to Ligado and predecessor companies for over 30 years — with those companies authorized to deploy terrestrially since 2004. . . . [O]ne of the FCC’s conditions require separation of Ligado’s operations from GPS spectrum by means of a 23-megahertz guardband. Thus, any implication that the Commission has authorized Ligado to ‘share’ spectrum that is currently allocated to GPS is incorrect. GPS has no right to operate in the spectrum in question, so there is nothing for Ligado to share.

“Moreover, your letter implies that the Department of Defense lacked an opportunity to present to the Commission, and in particular the Commissioners, technical information concerning the Ligado application. This is false. It is indisputable that the Department of Defense was provided with numerous opportunities over nearly a decade to provide the Commission with any relevant evidence it wished to submit.”

**To Be Continued**

The NTIA, the agency that advises the president on telecommunications policy issues, formally petitioned the FCC on May 22 to reverse its decision, making the request “on behalf of the executive branch, particularly the Department of Defense and the Department of Transportation.”

Dozens of industrial and end user organizations sent a letter to the FCC on June 3 supporting the NTIA petition for a stay of the FCC’s latest Ligado order. Various other groups have petitioned the FCC to reconsider its action. Some of these are listed on the coalition’s website <https://www.ion.org/gnss/registeration.cfm> for details.)

Moreover, recognizing the economic impact that COVID-19 has had on conference participation, the ION wants to make ION GNSS+ 2020 VIRTUAL affordable for all by offering ION’s reserve fund, established to provide financial stability for ION programs in unusual circumstances.

This discount will be applied during the electronic registration process.

**CGSIC Meeting**

As it has for many years, ION will again host the Civil GPS Service Interface Committee (CGSIC) meeting live streamed on the ION GNSS+ virtual meeting platform.

Visit <https://www.gps.gov/cgsic/meetings/2020> online for further details about this year’s CGSIC agenda.

PLANS 2020 Papers

Unfortunately, the pandemic has required the ION to again adjust its efforts to present content from this year’s Position Location and Navigation Symposium (PLANS 2020), which had been previously rescheduled from earlier this year to September. The biennial event is jointly sponsored with the IEEE Aerospace and Electronics Systems Society (AESS).

The ION originally planned to host as many of the originally scheduled PLANS 2020 presentations as possible in conjunction with ION GNSS+. With conversion of the GNSS+ event to a virtual format, however, we will be unable to do so. Further, because the IEEE/ION PLANS 2020 proceedings have been produced, indexed, and are 100 percent owned by IEEE, it would not be appropriate for ION to host these papers on an international virtual platform.

At this time, therefore, the ION has no plans to reschedule PLANS 2020 or host papers from this conference in the future. However, we sincerely congratulate the PLANS 2020 award winners listed in the article on page 21 in this issue.

Hotel and Flight Cancellations
We urge those who have already made arrangements to attend the meeting in person to expedite flight cancellations and contact the hotel directly to cancel your room reservation. ION will communicate directly with scheduled program participants, registered attendees, and exhibitors.

We ask for your patience as we reach out to you individually and work to address questions and provide additional information. Questions from currently registered and future attendees or representatives of the media may be directed to the Institute of Navigation by email at <membership@ion.org> or <registration@ion.org> or by phone at +1-703-366-2723.

We are excited and looking forward to your participation in ION GNSS+ 2020 VIRTUAL.
13-year-long effort to make the U.S. geodetic reference frame more accurate and stable using space-based positioning technology will take a little longer than originally planned.

On June 22, the National Geodetic Survey (NGS) announced a delay in the release of the modernized National Spatial Reference System (NSRS), which had originally been planned for completion in 2022. The NGS is the branch of the National Oceanic and Atmospheric Administration (NOAA) charged with maintaining the associated horizontal and vertical datums that surveyors and other professionals use to measure and position geographical assets within the United States. “Since 2017, operational, workforce, and other issues have arisen and compounded, causing NGS to recently re-evaluate whether a successful roll-out by 2022 is possible,” the NGS said in a public statement. “The most significant impacts have been in workforce hiring and retention, and in meeting GRAV-D data collection milestones, which underpin the NSRS modernization efforts.” GRAV-D is a gravity-based vertical datum resulting from an extensive GNSS-positioned gravimetry campaign that will be accurate at the two-centimeter level for much of the country.

The NGS added that it “is currently conducting a comprehensive analysis of ongoing projects, programs, and resources required to complete NSRS modernization and will continue to provide regular updates on our progress.” The resulting system will provide time-dependent height, latitude, longitude, scale, gravity, and orientation. The project will create four new reference planes and a geopotential datum, the North American-Pacific Geopotential Datum of 2022 (NAPGD2022), that will contain all of the necessary information to provide mutually consistent orthometric heights, geoid undulations, gravity anomalies, deflections of the vertical and all other geodetic coordinates related to the gravity field.

NGS officials admit that they don’t exactly know when the new NSRS will now be available, but say that “it is not out of the question to consider a complete roll-out of the modernized NSRS to be somewhere in the 2024–2025 time frame.” The modernized NSRS and associated measurement systems to be based on it will, however, retain the 2022 naming convention.

**Taking Advantage of New PNT Technology**

The NSRS modernization effort would enable the NGS to update the North American Datum (NAD83) and North American Vertical Datum (NAVD88) created in the 1980s using terrestrial surveying techniques constrained by some 600 Transit satellite Doppler observation points before the advent of GPS and other global navigation satellite systems (GNSSs). The datums support a network of control points on which surveyors and other positioning professionals base their measurements for such things as boundary surveys and geographic information systems (GIS).

Ground-based survey technology is subject to tectonic plate movements and subsidence caused by removal of oil, gas, and water beneath the ground. As a result of these and other physical movements, over time the datums and their net-
work of survey monuments become less accurate. According to the NGS, NAD83 is non-geocentric by about 2.2 meters and NAVD88 is both biased (by about one-half meter) and tilted (about 1-meter coast to coast) relative to the best global geoid models available today.

In particular, the deterioration in NAVD88 accuracy increases as one moves from the southeastern United States to the northwest. So, for example, portions of the Pacific Northwest measure up to five feet lower in geoidal height (relative to sea level) with NSRS22 rather than NAVD88. The accompanying graphic shows this tendency toward increasing regional inaccuracy by representing the difference between NAVD88 as a datum and the geopotential (geoid) surface used in the gravimetric geoid that will be reflected in NAPGD2022.

Space-based GNSS, on the other hand, operates in a stable geocentric coordinate frame and supports “active control” provided by continuously operating reference stations (CORS) maintained by the NGS and other government agencies to provide near–real-time accurate measurements. The NSRS will incorporate data directly and indirectly based on other GNSS besides GPS, such as Russia’s GLONASS, Europe’s Galileo, and China’s BeiDou.

GRAV-D — formally, Gravity for the Redefinition of the American Vertical Datum — will measure geoidal height along the direction of gravity, which, in turn, is based on the distribution of mass. Users will access the NSRS through the NOAA CORS Network by connecting their own GNSS surveys to the CORS Network using tools such as NGS’ Online Positioning User Service (OPUS).

In addition to GPS, the GNSS-derived components of the modernized NSRS will be aligned to the International Terrestrial Reference Frame (ITRF), as defined by the International Association of Geodesy (IAG).

CALL FOR NOMINATIONS
Nominate a Colleague for ION Fellows and Annual Awards

Submit your nominations today for ION’s Fellows and Annual Awards at www.ion.org/awards. All nominations must conform to ION nomination guidelines. Details of the nomination process and forms are available at <www.ion.org/awards>. Nominations must be received in proper form by October 15th to be considered.

The Institute accepts nominations for the following annual awards:

Per Enge Early Achievement Award
recognizing an individual early in his or her career who has made an outstanding achievement in the art and science of navigation.

Superior Achievement Award
recognizing individuals who are practicing navigators and have made outstanding contributions to the advancement of navigation.

Distinguished PTTI Service Award
recognizing outstanding contributions related to the management of PTTI systems.

Captain P.V.H. Weems Award
recognizing contributions to the art and science of navigation.

Tycho Brahe Award
recognizing outstanding contributions to the science of space navigation.

Norman P. Hays Award
recognizing outstanding encouragement, inspiration and support contributing to the advancement of navigation.

Colonel Thomas L. Thurlow Award
recognizing outstanding contributions to the science of navigation.

Election to Fellow membership
recognizes the distinguished contribution of ION members to the advancement of the technology, management, practice and teaching of the arts and sciences of navigation, and/or for lifetime contributions to the Institute.
Notwithstanding my admonitions stated in the Historian column in the Fall 2018 newsletter—that selecting the greatest all-time contributors to navigation is an exercise fraught with futility—I succumbed again to the irresistible temptation to create a Navigation Hall of Fame.

As you may recall, the ground rules set in that 2018 article were that the nominees had to have lived and worked at least 50 years or more in the past. The 10 men, and they were all men, I selected were:

- Eratosthenes (276–194 B.C.)
- Claudius Ptolemy (100–170 A.D.)
- Nicolaus Copernicus (1473–1543 A.D.)
- Ferdinand Magellan (1480–1521 A.D.)
- Piri Reis (1465–1553 A.D.)
- Galileo Galilei (1564–1642 A.D.)
- Isaac Newton (1643–1727 A.D.)
- Nathaniel Bowditch (1773–1838 A.D.)
- Elmer Sperry (1860–1930 A.D.)
- Albert Einstein (1879–1955 A.D.)

Each of these people left a legacy that made a lasting stamp on navigation for future generations.

More Than One-Hit Wonders

Although we may primarily remember these notable navigators for a singular discovery or achievement, almost without exception these men had numerous accomplishments that built their legacy.

Consider, for example, Eratosthenes. Known principally in our navigation community for his remarkable estimation of the radius of the Earth, Eratosthenes also invented an algorithm to determine prime numbers, measured the degree of obliquity of the ecliptic, and is thought to have created the armillary sphere (an early astronomical device for representing the great circles of the heavens).

Few of us have given any thought to what our legacy might be after we have passed. Part of the reason is that pondering our personal legacy is a somewhat morbid exercise. Another consideration is the difficulty of establishing a reputation that endures as the rate of technological change has drastically increased over the last century and accelerated drastically over the last two decades.

Picking Up the Pace

This relentless acceleration (or perhaps a more navigationally appropriate and metaphorical term would be relentless jerk) of our way of life over the past few generations has made focusing on anything, especially something as ephemeral as a legacy, nearly impossible. The technological revolution that we find ourselves in the midst of has undeniably made life more convenient, improved our generation and coordination of information, and enabled our access to new forms of entertainment, shopping, banking, and communication.

But has technology paradoxically made the concentration that is so necessary to distinguish oneself in intellectual fields more problematic? Just think back over the last few decades, if you are old enough, how everyday life has been altered by fax machines, beepers, and palm devices for personal organization, (now already almost outdated), home computers, cell phones, cell phones with cameras,
smart phones, laptops, 24/7 connectivity, the Internet and its world wide web. And, of course, email, Twitter, Instagram, Snapchat, Facebook, TikTok, and so on. All available wirelessly.

The cumulative achievement necessary to create a legacy may not be possible in the face of all this multiplexing as one innovation is rapidly overtaken by the next best thing. After all, Albert Einstein, whose Theory of General Relativity is often cited as humanity’s foremost intellectual achievement, famously refused to even answer his (land line) telephone.

Expand the Circle

Ultimately, it would be sad, unfair and unsatisfying to truncate the Navigation Hall of Fame with only gentlemen whose contributions were at least 100 years in the past — especially now that women are making their mark in the field. Unfortunately, although I personally took on the task of proposing the first 10 selectees, the identification of the next group of inductees is a responsibility too dire for a timid navigation historian. So, I hereby solicit nominations from readers of this newsletter.

In honor of the 75th anniversary of the Institute of Navigation, I will kick off the nominations with Captain Philip Van Horn Weems (March 29, 1889 — June 2, 1979). Weems was an individual who clearly thought about his navigation legacy. He was a U.S. Navy officer, inventor of navigational instruments and methods including the Weems Plotter and the Second Setting Watch, and author of navigational textbooks.

Weems was one of the original organizers of the Institute of Navigation and founded the Weems and Plath, Inc. marine supply store in Annapolis, Maryland. In a future Historian article, his many navigation contributions will be revealed in more detail.

Marvin B. May is a Professor Emeritus of Navigation at the Pennsylvania State College and is the 2006 winner of the Institute of Navigation’s P.V.H. Weems award for continuing contributions to the art and science of navigation. His emails are mayven4@comcast.net and mbm16@psu.edu. Nominations for the Navigation Hall of Fame may be sent to the above emails.

Check out my rough draft video on the history of inertial navigation at <https://youtu.be/epdmOdLAhSc>.
Defense Matters

Quantum Technology (and PNT)

We need to be aggressive to stay in the lead.

We certainly are living in challenging times.

I characterize myself as being an optimistic person — one who strives to find the positives when confronted with things that on the surface are conveying messages of gloom and doom.

But I have to admit that these past five months of social distancing and working from home, while listening to the evening news, has at times tested that optimistic outlook.

Seeking to stay in the subject area of this Defense Matters column, and sticking to the topic of positioning, navigation, and timing (PNT), daily news clips include a range of national and international challenges to GPS: the FCC’s recent decision to allow Ligado to move forward with a terrestrial network of transmitters in the spectrum adjacent to the GPS L1 frequency, the GPS jamming problems attributed to Russia persisting in northern Norway, the successful Chinese launch of a GEO satellite in late June that made their BeiDou-3 system fully operational — just to name a few.

On numerous fronts, the news that we are experiencing nearly every day across any number of subjects can cause even the most optimistic to pause and ponder where we are headed.

On the Bright Side

One area, however, that does show promise for the future, particularly for PNT, is quantum-enhanced processing and sensor technologies.

A recent essay posted on the Analytics Insight website <www.analyticsinsight.net> caught my attention. The title of the article is “When Will Quantum Computing Come to the Mainstream?”

The article provides a glimpse of how companies such as IBM are making progress in the development of quantum computing systems for commercial use.

Quantum computer based on superconducting qubits. The device shown here will be inserted into a dilution refrigerator and cooled to a temperature less than one degree kelvin. This part was built at IBM Research in Zurich, Switzerland, in collaboration with IBM Thomas J. Watson Research Center in Yorktown Heights, New York.

As the Analytics Insight author notes, “Quantum computing could have the potential to change the field of cryptography, and encryption codes could be broken quickly and possibly crushing blockchain technology if usable quantum computing were acces-
sible. The fields of Chemistry, Medicine and Pharmacology would shift to the next level with this dramatic leap in computing power, potentially providing real solutions to climate change, food production and drug discovery.

Investigating further, I located an October 2019 press release in which scientists at Google stated that, “its [Google’s] quantum computer carried out a specific calculation that is beyond the practical capabilities of a regular, ‘classical’ machine.” The release <https://ai.googleblog.com/2019/10/quantum-supremacy-using-programmable.html> stated, “Our machine performed the target computation in 200 seconds, and from measurements in our experiment we determined that it would take the world’s fastest supercomputer 10,000 years to produce a similar output.”

Not wanting to be one-upped by Google, an IBM blog <www.ibm.com/blogs/research/2019/10/on-quantum-supremacy> provided a retort, “Recent advances in quantum computing have resulted in two 53-qubit processors: one from our group in IBM and a device described by Google in a paper published in the journal Nature. In the paper, it is argued that their device reached ‘quantum supremacy’ and that ‘a state-of-the-art supercomputer would require approximately 10,000 years to perform the equivalent task.’ We argue that an ideal simulation of the same task can be performed on a classical system in 2.5 days and with far greater fidelity. This is, in fact, a conservative, worst-case estimate, and we expect that with additional refinements the classical cost of the simulation can be further reduced.”

The Classics Quantified

So, what do the authors mean by quantum versus classical computers?

Quantum computers work in a fundamentally different way from classical digital computers. A classical computer’s binary building block is the bit, which exists either as a 1 or a 0. A collection of eight bits, a byte, can represent a single character, such as the letter “A.” In the case of a quantum computer, the foundational building block is the quantum bit, or “qubit.”

The difficult thing to comprehend in quantum computing is that a qubit can exist in multiple states simultaneously. Whereas a digital computer processes bits that may exist as one of only two discrete values, a pair of qubits can hold four values at the same time. As the number of qubits grows, a quantum computer becomes exponentially more powerful — three qubits hold eight values, four qubits hold 16, and so on.

In the October 2019 Google press release, the calculation was performed using a 53-qubit processor that generates

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a 53-digit string of 1s and 0s — with a total of 253 possible combinations.

So, What’s It Mean for PNT

Bringing the application of quantum technology into the PNT realm, I refer readers to a March 12, 2020, news item on the Department of Defense (DoD) website titled, “DoD Should Focus on Short-term Goals in Quantum Service.”

The article, written by C. Todd Lopez, discussed testimony before the House Armed Services Committee by the now former Undersecretary of Defense for Research and Engineering, Dr. Michael Griffin.

As part of his submitted testimony, Dr. Griffin wrote, “First and foremost [are] quantum clocks to give us timekeeping, precision, synchronized timekeeping and precision [that are] two, or possibly even three, orders of magnitude better than we have today.” And, he continued, “That’s critically important for maintaining communications in a GPS-denied environment where we might have to fight a war.”

In keeping with Dr. Griffin’s vision, the 2020 Position Location and Navigation Symposium (PLANS), unfortunately rescheduled and then cancelled due to the COVID-19 pandemic, had planned a session on “Complementary PNT” that would have addressed “navigation technologies and techniques that replace, or supplement, traditional GPS/INS solutions for overcoming challenges in degraded or denied GPS environments.”

Now only available in the IEEE/ION PLANS 2020 proceedings, this session included papers on vision-aided navigation, exploitation of naturally occurring signals that would be immune to denial of service by an adversary, and, in addition to the clocks mentioned by Dr. Griffin, high precision quantum-enhanced inertial sensors among other possible sources of PNT information.

These developments in quantum computing and complementary PNT only serve to highlight and add credence to the DoD’s recent initiatives toward flexible, agile, easily modified combinations of PNT capabilities integrated into DoD systems using a Modular Open-System Approach (MOSA) strategy. Pursuing this emergent strategy will enable the Joint Force to benefit from resilient configurations of PNT and ultimately represents the entry point for exploitation of quantum-enabled PNT for all DoD platforms and systems into the future.

Optimistically, all that needs to happen to protect the Warfighter’s PNT capability is to remain focused on the goal. If we maintain that commitment in the long haul, we will get through this.
In an environment of increasing intentional and unintentional interference to GNSS systems, Congress and the Trump administration are advancing parallel and somewhat overlapping initiatives to expand the capacity of diverse technologies to provide assured (or alternative) positioning, navigation, and timing (APNT) as a backup to GPS.

A key issue is whether the public sector will take responsibility for implementing a backup system or leave it to industry and end users to come up with solutions.

The congressional initiative stems from a couple of legislative mandates: a series of National Defense Authorization Act (NDAA) bills dating beginning with Fiscal Year (FY) 2016, which requires the Department of Transportation (DoT) — in cooperation with the Department of Defense (DoD) and Department of Homeland Security (DHS) — to study and conduct a demonstration of backup GPS capability and complementary PNT (positioning, navigation and timing) services, and the National Timing Resilience and Security Act of 2018, which directs the DoT to establish and operate a “land-based, resilient and reliable alternative timing system.” The FY2020 NDAA extends the timeline for completion of the backup GPS demonstration.

On February 12, President Donald Trump signed Executive Order 13905 to establish a comprehensive national policy promoting the use of PNT services by the federal government and critical infrastructure owners and operators to strengthen infrastructure resilience. The executive order notes how GPS and other GNSSs have become “a largely invisible utility for technology and infrastructure,” including the electrical power grid, communications infrastructure and mobile devices, all modes of transportation, precision agriculture, weather forecasting, and emergency response.

“Because of the widespread adoption of PNT services, the disruption or manipulation of these services has the potential to adversely affect the national and economic security of the United States,” the order notes in supporting the need for developing assured PNT capacity in the United States.

In March tests at NASA’s Langley Research Center and Joint Base Cape Cod in Buzzards Bay, Massachusetts, 11 companies demonstrated a variety of potential backup PNT technologies, including map-matching, terrestrial RF (including enhanced Loran), satellite, and fiberoptic.

Analysis of the results of those tests was completed in May and will be presented to the National Space-Based PNT Executive Committee (EXCOM), which is co-chaired by the deputy secretaries of Transportation and Defense and provides interagency oversight for GPS-related matters. A recommendation on what the backup system should look like will be submitted in a report to Congress later.

“Knowing the diverse nature of the critical infrastructure sectors that rely on positioning, navigation and/or timing, it’s unlikely there is one solution that can meet everyone’s needs,” Karen Van Dyke, director of DoT’s office of PNT and spectrum told Inside GNSS magazine earlier this year. “Even GPS itself can’t meet all of the needs, particularly indoors and underground — some of the more impeded environments.”

“We are seeking the best solutions to ensure that America has a combination of PNT systems which, when used together, will be difficult to disrupt,” DoT Deputy Assistant Secretary for Research and Technology Diana Furchtgott-Roth told attendees at the Civil GPS Service Interface Committee that preceded the ION GNSS+ 2019 last September. “This effort will inform implementation of a system that is, to the maximum intent possible, required to be terrestrial, wireless, have wide area coverage, be difficult to disrupt and capable of expansion to provide positioning and navigation services. We might not be able to do all those things but we are very much going to try our best.”

**DHS View: User DIY Backup**

On April 8, as part of its efforts to address the congressional mandates, DHS released its “Report on Positioning, Navigation, and Timing (PNT) Backup and Complementary Capabilities to the Global Positioning System.” The report is a summary and analysis of an “in-depth assessment” of PNT systems currently used in the United States for DHS and DoT conducted by the Homeland Security Operational Analysis Center (HSOAC).

The HSOAC assessment provides

continued on page 16
recommendations for the federal government’s next steps in efforts to increase the resilience of U.S. Critical infrastructure to disruption of GPS services. Whatever approach or approaches to GPS backup are adopted, DHS recommends that “responsibility for mitigating temporary GPS outages be the responsibility of the individual user and not the responsibility of the Federal Government.”

“Research by HSOAC shows that users can mitigate short-term GPS disruptions (e.g., inability to read a GPS signal) with various strategies, ranging from using local backup capabilities to delaying operations until GPS is restored,” DHS stated.

As for longer term, the report recommends the following:

**PNT Diversity and Segmentation:** The Federal Government should encourage adoption of multiple PNT sources, thus expanding the availability of PNT services based on market drivers. Encouraging critical infrastructure owners and operators to adopt multiple PNT systems will diffuse the risk currently concentrated in wide-area PNT services such as GPS. Federal actions should focus on facilitating the availability and adoption of PNT sources in the open market.

**System Design:** PNT provisioning systems, assets, and services must be designed with inherent security and resilience features. Critical Infrastructure systems that use PNT services must be designed to operate through interference and to identify and respond to anomalous PNT inputs. These attributes are applicable to the PNT receivers and the systems that use them.

**Pursue Innovation that Emphasizes Transition and Adoption:** Incorporating PNT signal diversity into the PNT ecosystem should be pursued with an emphasis on research and development that prioritizes successful transition and adoption into existing GPS receivers, taking into account factors such as business case considerations, financial costs, technical integration, and logistical deployment.

The DHS report concludes that its research demonstrates that “there is no single intervention that the U.S. Government can make to ensure risk elimination of a GPS disruption. However, there are smart, market-oriented solutions that will contribute to enhanced resilience that the U.S. Government should continue to promote, enable and stimulate.”

Instead, the report suggests, DHS’s analysis leads it “to conclude there are steps the U.S. Government can take in the near term, in concert with industry, to enhance PNT resilience that would be more effective than endorsing and investing in a single backup system. Government and industry can achieve effective risk mitigation by influencing owner and operator planning and investment, broadening education efforts about the criticality of PNT services, enabling innovation in the market space, working to promote technical interoperability and adopting the principles contained in Executive Order 13905, Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services.”
Corporate Profile
Jackson Labs Technologies, Inc.
jackson-labs.com

Jackson Labs Technologies, Inc. is a privately held company that designs and manufactures precision Timing, Frequency, and Test & Measurement instruments based on the latest RF, Microprocessor, and Software technologies. Jackson Labs Technologies, Inc. strives to provide extraordinary electronic instruments that consistently outperform competitive products at price points that allow users with tight budgets to purchase our equipment. Jackson Labs Technologies, Inc. continuously cooperates with well-known industry experts and customers to test, certify, and improve its’ products.

For more information on corporate membership in the Institute of Navigation, please contact Kenneth P. Esthus at 703-366-2723 extension 1004

Calendar of Upcoming Events

SEPTEMBER 2020
8-11: ION Joint Navigation Conference (JNC) 2020, Northern Kentucky Convention Center, Greater Cincinnati, Ohio and AFIT, WPAFB, Dayton, Ohio
Contact: ION
Web: ion.org

21-25: ION GNSS+ 2020, St. Louis Union Station Hotel, St. Louis, Missouri
IEEE/ION PLANS 2020 technical program to be hosted in parallel at ION GNSS+, St. Louis Union Station Hotel, St. Louis, Missouri
Contact: ION
Web: ion.org

JANUARY 2021
Contact: ION
Web: ion.org

APRIL 2021
19-22: ION Pacific PNT Meeting (PNT) 2021, Hilton Waikiki Beach, Honolulu, Oahu, Hawaii
Contact: ION
Web: ion.org

JUNE 2021
1-4: ION Joint Navigation Conference (JNC) 2021, Northern Kentucky Convention Center, Greater Cincinnati, Ohio and AFIT, WPAFB, Dayton, Ohio
Contact: ION
Web: ion.org

SEPTEMBER 2021
20-24: ION GNSS+ 2021, St. Louis Union Station Hotel, St. Louis, Missouri
Contact: ION
Web: ion.org

NOVEMBER 2021
Contact: RIN
Web: www.rin.org.uk

SMC Awards for the Joint Modernized GPS Handheld Device

T he United States Space Force’s Space and Missile Systems Center (SMC) has awarded three separate “rapid prototyping” agreements to companies proposing to develop improved handheld GPS devices for military users.

The firm-fixed price agreements — awarded on June 26 to Collins Aerospace, Raytheon Intelligence & Space, and Technology Advancement Group, Inc. — call for design and production of basic working prototypes of the Joint Modernized Global Positioning System Handheld device. The contracts with a total value of $41.1 million are designed to provide the Department of Defense with innovative solutions demonstrated via hardware and software prototype development.

The purpose of this rapid prototyping effort is to produce a Joint Modernized Handheld device smaller in size with low power consumption, increased military-code capability, and improved anti-jamming and anti-spoofing capabilities compared to the equipment currently used by the military.

These agreements call for four demonstrations to be held with Army and Marine Corps representatives, providing an early opportunity for users to offer feedback and the ability to influence the final design.

“This is the first major update to the military’s GPS handheld device in more than 15 years,” says Col. Clifford Sulham, SMC’s User Products Division chief.
This column features one of ION's Technical Representatives each quarter to highlight the depth and breadth of their work, research, and interests. During their two-year terms, the ION's Technical Representatives guide and advise The Institute of Navigation and the positioning, navigation, and timing (PNT) community. — Interview and write-up by Dr. Kyle Wesson

Most likely by the time you receive this newsletter, Terry Moore will have retired from his professorship at the University of Nottingham as the Director of the Nottingham Geospatial Institute. He is leaving behind a university much changed as a result of the impact of the COVID-19 pandemic: classes have moved online or into small groups, major tests need to be reassessed, and research in laboratories with access to physical hardware is facing new challenges.

Although we spoke just a month before his departure, Terry was clearly not slowing down anytime soon. He is still the President of the Royal Institute of Navigation and a member of Council of the ION, the U.S. PNT Advisory Board, the UK PNT Strategy Working Group, and the Galileo Science Advisory Committee of the European Space Agency.

So much for retirement!

That said, Terry is looking forward to continuing to cycle locally and hike in the Alps (shown in accompanying photo with his son on the slopes) where his family still has travel plans this summer. Until the next in-person ION conference, please read on to learn more about Terry and get to know him a little better.

1. How did you first get involved with ION?

My first contact with the ION was when I attended the ION GPS ’93 conference held in Salt Lake City. This was, I think, the 6th International Meeting of the Satellite Division, and the first time the conference was held in Salt Lake City. I presented a paper entitled “GPS Coordinates as a GIS Attribute” co-authored with my mentor and colleague Professor Vidal Ashkenazi. It was the first time I met many colleagues who have now become such good friends over the years.

2. What is your favorite aspect of being a member of ION?

The opportunity to meet such great people and friends through the conferences and other events. The majority of my international network has been built on friendships made during ION meetings. The conferences really are outstanding, and they have been the core of my engagement with the PNT community over many years.

3. What type of GNSS work do you do currently, or have you done in the past?

My PNT research interest has been incredibly varied over many years and has evolved over time as technology has changed and so my interests have...
changed. In reality, I have done little research work myself, but I have had the pleasure to work with and supervise outstanding colleagues and research students. There is so much pleasure to have a novel thought and seeing it researched, implemented, and tested by such great talent. This is what keeps work still exciting and original. I’m currently supervising projects across a range of PNT and GNSS topics ranging from multi-constellation, multi-frequency PPP, integrated systems, indoor/pedestrian navigation and autonomous vehicles.

4. What do you consider some of the most important current research, education, policy, or technical topics in GNSS for the next year?

There is so much to be done to ensure that we really address the robustness of PNT. There is, of course, technical work we can do to progress the development of a system of systems philosophy for robust PNT, but so much work needs to be done to educate and inform user communities, policy, and governance makers. PNT is at the core of our lives and our societies, and we need to ensure it gets the appropriate attention to allow us to provide safe and secure positioning, navigation, and timing for everyone. The COVID-19 pandemic has further highlighted the role that PNT plays in our lives and has brought a further attention on the privacy and ethics aspects of the use of our technology.

5. What areas of ION have you been involved in, and what areas do you hope to see grow in the future?

I have been actively involved with ION, and in particular the Satellite Division, for many years. I’ve been a member of ION Council since 2013. I was the Program Chair of ION GNSS+ 2014 and General Chair of ION GNSS+ 2015, and I have been session/panel chair on many occasions at numerous ION conferences. I was the Chair of the Awards Committee in 2015 and 2016 and Chair of the Kepler Award Committee in 2018. For the last few years, I have been Co-Chair of the Peer Review Committee for the ION GNSS+ conferences. I am also currently the President of the Royal Institute of Navigation, and it has been my pleasure to act as a liaison point between the two institutes to foster greater and closer collaboration. I think that now more than ever before we all need to work together to make the world a better and safer place to live, and navigation has a key role to play.

6. If you were not in your current field, what would you want to do for a living?

I have always been fascinated with cosmology and fundamental physics, but I have no real knowledge or experience on which to say this could have been the basis of an alternative career. I can’t really see that any other of my real interests could probably earn me any money! I am, and always have been, a musician, which I would love to have developed further, but I doubt I could have made this into a profession, apart from busking for pennies on a city street. My other great passions are mountaineering, hiking, and travel. I would love to have followed these as a career, making a living from travel writing and public speaking. The great outdoors gives me the space to live and to think, and it is there where I rest and feel at peace. Let’s all go for a walk!
Dr. Javad Ashjaee (1949–2020) passed away in Moscow on May 30 from COVID-19. An early pioneer in GPS receiver development, he spearheaded advancements in both GPS and GPS/GLONASS receivers, first at Trimble and later at his own Ashtech where he was the first to integrate GLONASS with GPS commercial receivers. After selling Ashtech, he founded Javad Navigation Systems which was partially sold to Topcon to start Topcon’s GPS Division. Javad then started JAVAD GNSS where he added Galileo, BeiDou, and QZSS lines to his high-precision equipment offerings. He is credited with permanent contributions to the geodetic surveying industry.

Javad was actively involved in ION for many years. He presented numerous papers at ION conferences and published in NAVIGATION. He was also a central figure at the early ION GPS meetings, easily located with the largest exhibit booth in the center of the exhibit show floor. Javad never did anything small — it was always BIG or not at all. He was credited for being generous with the ION GPS conference and exhibition while it was still in its infancy and was one of the personalities that helped ION expand the reach of the ION GPS event from a national to an international audience.

Ronald Braff, 85, of Annandale, Virginia, passed away on April 13, 2020. Mr. Braff began his career with the FAA in 1962 and joined The MITRE Corporation in 1970 where he continued to advance the state-of-the-art in navigation systems and he made numerous influential contributions in the applications of radio navigation to aircraft. These included VORTAC modernization, Loran and Omega application to the National Airspace System, and GPS augmentation.

He conceived of the GPS Integrity Channel (GIC) that was the precursor to satellite-based augmentation systems (SBAs) that are widely deployed today. He also influenced the design of Selective Availability to maximize the early benefits of GPS to aviation. In recent years, he contributed to integrity improvements for GPS modernization programs including GPS III and OCX.

Mr. Braff was a prolific author and was justifiably proud of having papers published in the ION’s quarterly journal NAVIGATION every decade from the 1960s through as recently as this year. He served as editor of NAVIGATION from 1986 to 1996. He received the ION’s Hays and Distinguished Service Awards and was a Fellow of both the ION and the Royal Institute of Navigation.

The Satellite Division Nominating Committee, chaired by Dr. Frank van Diggelen, has submitted the following nominations for Satellite Division Officers:

Chair:
Ms. Patricia Doherty, Boston College

Vice Chair:
Ms. Sandy Kennedy, Hexagon Positioning/NovAtel, Canada
Mr. Tim Murphy, Boeing

Secretary:
Dr. Mohammed Khider, Google
Dr. Tyler Reid, Xona Space Systems

Treasurer:
Dr. Jihye Park, Oregon State University
Dr. Demoz Gebre-Egziabher, University of Minnesota

Online voting for the ION Satellite Division Officers will be available after July 17. Completed ballots must be received at the ION office by August 7, 2020, in order to be counted.

Election results will be announced during the 33rd International Technical Meeting of the ION Satellite Division being held September 21-25, 2020. The newly elected officers will take office on September 25, 2020, at the conclusion of the meeting and will serve for two years. Election results will be reported in the ION Newsletter.
IEEE/ION AESS PLANS Awards Recipients

The following awards were to have been presented during the IEEE/ION PLANS 2020, an event originally scheduled for April but cancelled due to COVID-19. However, the program and awards committees decided to proceed with best paper awards, as peer reviews had been completed. The ION will also index the IEEE/ION PLANS proceedings in IEEE Xplore as intended.

Technical paper awards were selected based on peer review conducted on papers reviewed for IEEE/ION PLANS 2020 in April by an independent PLANS awards committee.

The IEEE Kershner Award

The IEEE Kershner Award is awarded for outstanding achievement and contribution to the technology of navigation and position equipment, systems or practices.

Awarded to: Dr. Y. Jade Morton
Citation: For her contributions to the advancement of navigation receiver technology including event-driven multi-GNSS data collection systems; robust tracking under scintillation; reduction of errors due to oscillator frequency offsets, multipath, and interference; and as an educator whose passion for teaching and mentoring has benefited students throughout the world.

The IEEE Walter R. Fried Memorial Award

The Walter R. Fried Memorial Award is awarded for the best paper at IEEE/ION PLANS.

Automatic-Radar-Based 50-cm Urban Positioning: Lakshay Narula, Peter A. Iannucci, Todd E. Humphreys, Radio Navigation Laboratory, The University of Texas at Austin

PLANS Best Student Paper Award

Deep Learning-Aided Spatial Discrimination for Multipath Mitigation: Ali A. Abdallah and Zaher M. Kassas, University of California, Irvine

PLANS Best Paper Awards

Awards are presented to the lead authors of the best paper in each technical track. The selection criteria include: technical content; innovation; importance and timeliness of the subject matter; and conciseness, clarity and completeness of the written material. The following papers were selected:

Sub-Degree-Per-Hour MEMS Gyroscope for Measurement While Drilling at 300°C: David Lin, Robert MacDonald, Dorin Calbaza, Brian Scherer, Tammy Johnson, Tim Toepfer, David Shaddock, Emad Andarawis, GE Research, General Electric Company

Demonstration of a Multi-Layer Spoofing Detection Implemented in a High Precision GNSS Receiver: Ali Broumandan, Sandy Kennedy, John Schleppe, NovAtel Inc., part of Hexagon, Canada

Navigation with Differential Carrier Phase Measurements from Megaconstellation LEO Satellites: Joe Khalife, Mohammad Neinaeae, Zaher M. Kassas, University of California, Irvine


ION Webinar Series Adds Online Resource

Since introducing its Webinar series in December 2019, ION has produced six timely and engaging presentations on topics of interest to the PNT community.

Many of the webinars highlight and expand on prominent papers published in recent issues of NAVIGATION, Journal of the Institute of Navigation.

The following webinars have been recorded and are available FREE for online viewing at <www.ion.org/publications/webinars.cfm>:

Improving Environment Detection by Behavior Association for Context-Adaptive Navigation, presented by Dr. Han Gao and Dr. Paul Groves, University College London

When GNSS fails, what will you do? MarRINav! Presented by Jonathan Turner, NLA International; Alan Grant, General Lighthouse Authorities of the UK; and Dana Goward, Resilient Navigation and Timing Foundation (Co-sponsored by ION, the Resilient Navigation and Timing Foundation, and the Royal Institute of Navigation)

Impact of Sample Correlation on SISRE Overbound for ARAIM, presented by Dr. Santiago Perea, Airbus, Germany

Flight Results of GPS-Based Attitude Determination for the Canadian CASSIOPE Satellite, presented by Dr. André Hauschild, DLR’s German Space Operations Center (GSOC), Germany

Gaussian-Pareto Overbounding of DGNSS Pseudoranges from CORS, presented by Dr. Jordan D. Larson, Department of Aerospace Engineering and Mechanics, University of Alabama

LTE Receiver Design and Multipath Analysis for Navigation in Urban Environments, Kimia Shamaei and Zak Kassas, Autonomous Systems Perception, Intelligence, and Navigation (ASPIN) Laboratory, University of California, Irvine

To be notified of future webinars, members may sign up for ION’s email list or follow us on social media. Links to those options are available on the ION Webinars page.
**GNSS Program Updates**

**News from Systems Around the World**

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**GPS**

Even as approval of Ligado Networks terrestrial broadband network threatens GNSS L1 transmissions (see article on page 1), the United States continues to build out a modernized Global Positioning System.

On June 30, the U.S. Space Force and its mission partners successfully launched the third GPS III satellite, which incorporate a suite of new signals and features. The launch of the Lockheed Martin-built satellite from Cape Canaveral Air Force Station, Florida, was carried to orbit aboard a SpaceX Falcon 9 Launch Vehicle.

The GPS III Space Vehicle 3 (SV03) mission represents the first successful use of a recoverable Falcon 9 rocket. The first-stage booster of the Falcon 9 was successfully recovered approximately 20 minutes after liftoff by the company’s autonomous spaceport drone ship off the Atlantic coast.

After on-orbit testing, GPS III SV03 is expected to join the GPS constellation — including GPS III SV01 and SV02, which were declared operational in January and April — in providing positioning, navigation and timing signals for an estimated four billion-plus military, civil, and commercial users worldwide.

According to the U.S. Air Force, the new GPS IIIIs provide three times better accuracy and up to eight times improved anti-jamming capabilities over previous generations of GPS satellites. They also offer a new L1C civil signal, which is compatible with other international global navigation satellite systems, such as Europe’s Galileo, to improve GNSS availability and resilience for civilian users.

GPS III also continues the Space Force’s plan to field M-Code, a more-secure, harder-to-jam and spoof GPS signal for U.S. and allied military forces. GPS III SV03 brings the number of M-Code enabled satellites to 22 in the 31-satellite GPS constellation.

Until the GPS Next Generation Operational Control System (OCX) Block 0 becomes operational, the legacy Operational Control Segment (OCS) ground control system at Schriever Air Force Base, Lockheed Martin has been helping sustain the OCS with a series of software upgrades. These include the Red Dragon Cybersecurity Suite and GPS III Contingency Operations upgrade, which enabled the system to control the more powerful GPS III satellites.

In early June, Lockheed Martin installed the M-Code Early Use (MCEU) upgrade on the OCS. Expected to be operational by the end of this year, the MCEU upgrade will help accelerate M-Code’s deployment in order to support testing and fielding of modernized user equipment for military users.

According to the Raytheon Company, the OCX prime contractor, the system is expected to be completed by June 2021. The $6.2 billion OCX program is six years behind schedule and has cost $2.5 billion more than expected, according to a 2019 Government Accountability Office (GAO) report.

GPS III satellite production takes place at Lockheed Martin’s GPS III Processing Facility near Denver, Colorado. Currently, the production line has seven satellites moving through work cells, from assembly to test to storage, before they ship to Cape Canaveral. GPS III SV04 and SV05 are completed and declared “Available for Launch” by the Space Force. GPS III SV06, SV07, and SV08 are completely assembled on the production floor and currently going through post-assembly and environmental testing. GPS III SV09 and SV10 are in component build up.

Lockheed Martin has also begun work on the GPS III Follow On (GPS IIF) program, which could add up to 22 additional GPS IIF satellites with additional capabilities. In March, the GPS IIF program completed its Critical Design Review (CDR). GPS IIF builds off the existing modular GPS III, which was designed to evolve with new technology and changing mission needs. GPS IIF will add a new Regional Military Protection Capability, a fully digital navigation payload, an accuracy-enhancing laser retro-reflector array, and a new search & rescue payload.

**BeiDou**

China launched the final satellite of the BeiDou Navigation Satellite System (BDS) on June 23, completing deployment of the nation’s GNSS system.

The BDS-2 system began construction in 2004 to provide navigation and timing services over China and the Asia-Pacific region. Development of BDS-3 began in 2009 and provides global service.

By 2012, a total of 14 satellites, including five geostationary Earth orbit (GEO) satellites, five inclined geosynchronous Earth orbit (IGSO) satellites and four medium Earth orbit (MEO) satellites, had been launched to complete the deployment.

In 2012, the BDS began providing positioning, navigation and timing services to users in the Asia-Pacific region. In September 2015, China launched the first BeiDou satellite with an onboard hydrogen atomic clock.
In November 2017, China launched the first two satellites for the BDS-3 system, which started construction in 2009, and officially expanded its regional navigation system into a global network.

China launched the first GEO satellite of the BDS-3 system in November 2018, orbiting at about 36,000 kilometers above the Earth. By the end of that year, a total of 33 BDS satellites were operating in orbit and Beidou had started to provide global service. China completed deployment of the core BDS constellation by sending 10 BDS satellites into space in 2019.

Unlike other GNSSs, the Beidou constellation includes six spacecraft in geosynchronous orbits more than 22,000 miles (about 36,000 kilometers) above Earth, with three permanently over the equator and three others in inclined orbits that carry the spacecraft north and south of the equator during each day.

The June 23 launch was the 35th BDS-3 satellite placed in orbit since 2015 and the final geosynchronous spacecraft in the constellation. Beidou has 44 operational spacecraft, counting BDS-2 and BDS-3 satellites.

**GLONASS**

A new GLONASS-M satellite launched March 15 was commissioned for operational use on April 14. It operates to the Roscosmos Information and Analysis Center for Positioning, Navigation and Timing.

The spacecraft, designed and built by ISS-Reshetnev Company, entered service following the successful completion of on-orbit flight tests. It replaced another GLONASS satellite in orbital slot 24, plane 3, that had been operational for 10 years and was transferred a new status as an on-orbit spare.

Another GLONASS-M launch last December became operational in January.

The current GLONASS constellation includes 27 satellites, including 24 operational satellites, two on-orbit spares, and one satellite undergoing flight tests.

Nikolay Testyovdov, director general of ISS-Reshetnev Company, discussed GLONASS production at a December meeting hosted by the company for Russia’s Science and Technical Council. He said ISS-Reshetnev is under contract to produce 27 more GLONASS satellites to replenish the system through 2025. ISS-Reshetnev is based in Zheleznogorsk near the city of Krasnoyarsk in Siberia.

In a meeting of the International Committee on GNSS (ICG) last December, Ivan Revniykh, head of Roscosmos State Space Corporation’s GLONASS Application Division, described plans to implement a high-orbit component to the GLONASS constellation. It will be comprised of six next-generation GLONASS-K spacecraft in three orbital planes at an inclination of 64.8 degrees designed to provide improved coverage in restricted environments, urban canyons and the arctic region.

Launches are scheduled to begin in 2023 with the six satellites deployed by 2025 and broadcasting three open civil signals.

**Galileo**

The European GNSS program will resume satellite launches in December, two years since the last launch and 18 months after a weeklong system outage caused equipment malfunction in the Galileo ground infrastructure that affected the calculation of time and orbit predictions.

Two spacecraft are scheduled to be carried into orbit by Russian Soyuz ST-B rocket. Beginning in 2021, Ariane-space’s new Ariane 6 rocket will launch future Galileo satellites. Currently, 19 full operational capability satellites and three in-orbit validation satellites comprise the operational constellation.

The Galileo Open Service (OS) and SAR/Galileo Service Public Performance Reports for the first quarter of 2020 indicated that the European GNSS system exceeded its minimum performance level parameters in all categories.

In other developments, Carlo des Dorides retired as executive director of the European GNSS Agency (GSA) in January after nine years leading one of the three key organizations — along with the European Space Agency and the European Commission — responsible for Galileo and related space systems. Pascal Claudel, GSA’s chief operating officer and a former executive at Thales Alenia Space and Arianespace, is serving as the agency’s acting executive director while the search for a replacement for des Dorides is under way.

The GSA is responsible for the operations and service provision of Galileo and the European Geostationary Navigation Overlay Service (EGNOS) as well as promoting market development for both systems. The agency oversees the operation of such key service facilities as the Galileo Security Monitoring Center (GSMC) in France and in Spain and the European GNSS Service Center in Spain.

Meanwhile, ESA has awarded two contracts to Thales Alenia Space in support of system evolution of EGNOS. The first contract concerns possible upgrades for EGNOS aeronautical services, designed to improve performances in order to increase landing safety under limited visibility conditions (from current CAT-I to CAT-II), over the current EGNOS footprint, focused on Europe. The second contract will study changes required to extend its aeronautical services worldwide exploiting A-RAIM (Advanced Receiver Autonomous Integrity Monitoring) and the global coverage of the Galileo satnav constellation.
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