GPS WORLD

GNSS
POSITION
NAVIGATION
TIMING

GPSWORLD.COM

PNT Roundup

Unmanned Cars Hit Indy Track

PROTECTING PNT

Anti-jam receivers protect data, mitigate navigation warfare threats

Directions 2020

Top executives discuss where GPS, Galileo, BeiDou and GLONASS are headed

A NORTH COAST MEDIA PUBLICATION

DECEMBER 2019 | Vol 30 | No 12


TOPCON
TOPCON
TOPCON CORP

CONTENTS

VOL. 30 NO. 12 GPSWORLD.COM

DECEMBER 2019

COVER STORY

Artist's Concept: Collins Aerospace

Cover photo: Canada's Department of National Defence

Photo: BeiDou

SPECIAL SECTION

OPINIONS AND DEPARTMENTS

LAUNCHPAD

MARKET WATCH

No One Is in Charge

US Falling Behind Protecting GPS/GNSS, Civilian Users

BY DANA GOWARD
GUEST COLUMNIST

Europe's scattered monitoring of GNSS signals found almost 500,000 interference events over three years. About 59,000 were clearly intentional. European standards for resilient receivers have been published and acquisition of an interference detection network is underway.

Russia is improving its terrestrial Loran/Chayka PNT system for military use and has promised to make the upgraded service available to civilians.

China has retained its terrestrial Loran PNT system as an augmentation/backup for its BeiDou GNSS. It is also testing PNT satellites in low earth orbit (LEO) to provide more powerful and reliable signals than available from current GNSS.

In contrast to the actions of other countries, little is being done in the United States to protect civilian GPS/GNSS users.

The U.S. Department of Defense (DoD) has been very active protecting its own with GPS M-code signals and receivers. It is exploring use of LEO communications satellites and high-powered, low-frequency ground transmissions, such as Loran, to add to the GPS signals.

Yet DoD claims civilian use of GPS has limited its ability to use it as a military tool. It says it has no intention of sharing any new PNT systems with civilians.

At the same time, the 99% of GPS use in the U.S. that is non-military is arguably more important to the nation's safety and security. GPS signals are used by every networked technology and every mode of transportation. They are so important that officials at the Department of Homeland Security have called GPS "a single point of failure for critical infrastructure."

> "Putting someone in charge is key to reversing America's civil PNT decline."

The U.S. military recently updated its PNT strategy, has a designated leader for its PNT efforts, and clearly defines the responsibilities of its various staffs and organizations.

Civil agency responsibilities were last updated in 2004 and are spread across more than a dozen departments, agencies, and staffs.

Most significantly, no one is in charge.

This has meant that over the past 15 years, many of the civil mandates and responsibilities to protect signals and users have gone unfulfilled. As just one example, rather than ramp up to address increases in jamming, the Federal Communications Commission has reduced its enforcement equipment and staff.

Putting someone in charge is key to reversing America's civil PNT decline and energizing both federal and private stakeholders.

A single, empowered federal leader should be responsible, not for doing everything, but for leading and coordinating federal and other civil efforts. This would be someone to be held accountable, and to hold others accountable — an evangelist for the essentiality of these services, and their advocate at the highest levels of government.

Such a leader should be positioned outside the daily turmoil of the White

CONTINUED ON NEXT PAGE. >>

GPS WORLD
GNSS POSITION NAVIGATION TIMING
WWW.GPSWORLD.COM

EDITORIAL
Editorial Director Marty Whitford
mwhitford@northcoastmedia.net | 216-706-3766
Senior Editor Tracy Cozzens
tcozzens@northcoastmedia.net | 541-255-3334
Staff Editor Diane Sofranec
dsofranec@northcoastmedia.net | 216-706-3793
Digital Media Manager Allison Barwacz
abarwacz@northcoastmedia.net | 216-706-3796
Art Director Charles Park
charlespark@gmail.com | 858-337-8847

CONTRIBUTING EDITORS
General Matteo Luccio | *mluccio@northcoastmedia.net*
Innovation Richard Langley | *lang@unb.ca*
Defense PNT Michael Jones | *mjones@gpsworld.com*
Professional OEM & UAV Tony Murfin | *tamurfin@verizon.net*
GeoIntelligence William Tewelow | *wtewelow@gpsworld.com*
Survey Tim Burch & Dave Zilkoski | *tburch@gpsworld.com & dzilkoski@gpsworld.com*

BUSINESS
Publisher Marty Whitford
mwhitford@northcoastmedia.net | 216-706-3766
Senior Account Manager Mike Joyce
mjoyce@northcoastmedia.net | 216-706-3723
Account Manager Ryan Gerard
rgerard@northcoastmedia.net | 216-363-7921
Director of Audience Engagement Bethany Chambers
bchambers@northcoastmedia.net | 216-706-3771
Director of Marketing & Events Michelle Mitchell
mmitchell@northcoastmedia.net | 216-363-7922
Event Manager Allison Blong
ablong@northcoastmedia.net | 216-363-7936
Marketing & Sales Manager, Buyers Guide Emily Adkins
eadkins@northcoastmedia.net | 216-675-6006

PUBLISHING SERVICES
Manager, Production Services Chris Anderson
canderson@northcoastmedia.net | 216-978-5341
Senior Audience Development Manager Antoinette Sanchez-Perkins
asanchez-perkins@northcoastmedia.net | 216-706-3750
Reprints & Permissions Brett Petillo
bpetillo@wrightsmedia.com | 877-652-5295
Circulation/Subscriber Services
gpsworld@omeda.com | USA: 847-513-6030

NORTH COAST MEDIA LLC
1360 East 9th St, Tenth Floor
Cleveland, OH 44114, USA
President & CEO Kevin Stoltman
kstoltman@northcoastmedia.net | 216-706-3740
Vice President of Finance & Operations Steve Galperin
sgalperin@northcoastmedia.net | 216-706-3705
Editorial Director Marty Whitford
mwhitford@northcoastmedia.net | 216-706-3766
Vice President of Graphic Design & Production Pete Seltzer
pseltzer@northcoastmedia.net | 216-706-3737

MANUSCRIPTS: *GPS World* welcomes unsolicited articles but cannot be held responsible for their safekeeping or return. Send to: 1360 East 9th St, Tenth Floor, IMG Center, Cleveland, OH 44114, USA. Every precaution is taken to ensure accuracy, but publishers cannot accept responsibility for the accuracy of information supplied herein or for any opinion expressed. **REPRINTS:** Reprints of all articles are available (500 minimum). Contact 877-652-5295, Brett Petillo. Wright's Media, 2407 Timberloch Place, The Woodlands, TX 77380. **SUBSCRIBER SERVICES:** To subscribe, change your address, and all other services, e-mail gpsworld@omeda.com or call 847-513-6030. **LIST RENTAL:** Contact 800-529-9020, Brahm Schenkman, bschenkman@inforefinery.com, The Information Refinery, Inc. **PERMISSIONS:** Contact 877-652-5295, Brett Petillo. Wright's Media, 2407 Timberloch Place, The Woodlands, TX 77380. **INTERNATIONAL LICENSING:** E-mail gpsworld@gpsworld.com. **ACCOUNTING OFFICE AND OFFICE OF PUBLICATION:** 1360 East 9th St, Tenth Floor, IMG Center, Cleveland, OH 44114, USA. ***GPS WORLD*** does not verify any claims or other information appearing in any of the advertisements contained in the publication and cannot take any responsibility for any losses or other damages incurred by readers in reliance on such content.

Published monthly

NORTH COAST MEDIA LLC
VERIFIED

<< Continued from previous page.

House and National Security Council. They should be in the civil department with the portfolio that most depends on GPS and other PNT. The one that suffers first when GPS and other PNT are not available — the Department of Transportation (DOT).

DOT is already the federal interface with civil GPS users, and co-chairs the national PNT executive committee with DOD. A few edits to national policy and a few staff reassignments could establish a national PNT leader in DOT and make all the difference.

Regaining U.S. PNT leadership is essential to America's future security and prosperity. We must take the first step by appointing and empowering a single federal leader to make it happen.

Dana Goward is president of the Resilient Navigation and Timing Foundation (**rntfnd.org**).

PNT Q&A — EDITORIAL ADVISORY BOARD

What is or would be the best policy response from Congress and/or executive branch agencies to the growing threats to GPS from jamming and interference?

Bradford W. Parkinson
Stanford Center for Position, Navigation and Time

"Homeland Security has declared GPS to be an essential system to virtually all of our infrastructure. It is time to install a national system to identify and shut down interference. As part of that, all cell phones should periodically report interference to that national system and allow law enforcement to pinpoint and eliminate offenders."

Alison Brown
NAVSYS Corporation

"On Dec. 5, 2018, the president signed into law the National GPS Timing Resilience and Security Act tasking the Secretary of Transportation with establishing a backup timing system for GPS within two years. To date, only limited technology demonstrations have been performed. Congress needs to fund the Department of Transportation to rapidly acquire and deploy a back-up timing capability, using available commercial solutions, to assure resilience within the Air Traffic Control system and other critical infrastructure to GPS jamming or spoofing."

ESA to Use CORS for Global Error Mapping

A new European Space Agency (ESA) project will harness CORS networks to provide an ongoing overview of satnav performance globally and regionally. Hundreds of continuously operating receiver stations (CORS) are in place around the world.

"For safety-critical applications, we need to know exactly when systems are not performing optimally, and why," said Michael Pattinson of Nottingham Scientific Ltd. in the United Kingdom, who is developing the project for ESA. "Current performance monitoring is often partial, based around individual signal frequencies or constellations, carried out by the service operators themselves."

The new COLOSSUS (Crowd-Sourced Platform for GNSS Anomaly Identification, Isolation and Attribution Analysis) data platform is designed to provide the most detailed picture possible of overall performance from the user side, covering all satellite constellations, signal frequencies and receiver types.

"The aim is to immediately identify system failures, faults and other errors on an immediate, autonomous basis," Pattinson said. The project will gather and analyze positioning data from CORS networks worldwide. "By performing positioning continuously at a fixed site in the landscape, they can be used as a standard, serving to identify and subtract measurement errors to boost positioning accuracy on a localized basis."

Many CORS networks have been established for scientific uses, such as the worldwide International GNSS Station (IGS) network, used as a standard geographical reference and to measure shifts in the solid Earth, oceans and ice. Others have been set up by national mapping agencies, such as the Ordnance Survey in the United Kingdom. And private-sector networks improve the accuracy of services such as land surveying, air service or road charging.

Photo: Ordnance Survey

OS NET STATION: A CORS station in Tiree, the Hebrides, part of the Ordnance Survey's 110-strong OS Net network.

"We're talking to operators to allow us to access their data in exchange for sharing our results, and they're very interested in accessing such performance metrics," Pattinson said. "With measurements from so many sites, when a failure does occur we'll be able to pin down its likely source almost immediately."

The aim is to begin testing the cloud-based COLOSSUS towards the end of 2019 and bring the service online in the first few months of 2020.

China Launches BDS-3 Satellite

China sent a new satellite of the BeiDou Navigation Satellite System (BDS) into space from the Xichang Satellite Launch Center in Sichuan Province at 17:43:04 UTC on Nov. 5.

Launched on a Long March-3B carrier rocket, it is the 49th satellite of the BDS satellite family and the 24th satellite of the BDS-3 system.

It also marked that a total of three BDS-3 satellites have been sent into the inclined geosynchronous Earth orbit.

The launch was the 317th mission for the Long March series of carrier rockets.

The new satellites and the carrier rocket were developed by the China Academy of Space Technology and the China Academy of Launch Vehicle Technology, under the China Aerospace Science and Technology Corporation.

China will launch another six BDS-3 satellites to complete the BDS global network.

GEO-3 Hits Snag

At press time, Eutelsat Communications was still investigating an incident on one of the two solar arrays on its Eutelsat 5 West B satellite.

Launched Oct. 9, West B carries the EGNOS GEO-3 payload for the European GNSS Agency (GSA). GEO-3 is designed to be aboard a geostationary satellite to augment GNSS signals.

Eutelsat said it is "working to assess the potential impact on the performance of the satellite and will communicate on it as quickly as possible."

SENSOR FUSION

Universities Compete in New Autonomous Race

BY KEVIN DENNEHY
GPS WORLD CONTRIBUTOR

University teams will go head-to-head in a two-year autonomous race car competition to test new software and other self-driving technologies at Indianapolis Motor Speedway.

The competition, called the Indy Autonomous Challenge, culminates in a high-speed autonomous vehicle race, scheduled for Oct. 23, 2021, on the speedway's famed 2.5-mile oval track that is home to the annual Indianapolis 500.

The competition was inspired by the 2005 Defense Advanced Research Projects Agency (DARPA) Grand Challenge, which pitted university teams against each other and spurred commercial development of autonomous vehicles.

"The idea for the Indy Autonomous Challenge originated with DARPA's winning team captain, [Stanford University's] Sebastian Thrun. Sebastian joined us at the 2018 Indy 500, where he reflected on the inspiration and excitement that came from participating in the DARPA challenge, and how a high-speed automated vehicle race at the Indianapolis Motor Speedway had the potential to be on par with that experience with today's teams," said Matt Peak, Energy Systems Network director of mobility.

Like the DARPA competition, the Indy Autonomous Challenge focuses on university participation. "I can't speak for DARPA, but our focus on universities is deliberate," Peak said. "It was advised by not only Thrun, but other original DARPA competitors such as [Aurora CEO] Chris Urmson, all of whom commented on how participation by universities — their students, faculty, departments, alumni — was a key to DARPA's success."

The autonomous racing software developed through the competition could assist in developing commercial self-driving vehicles and enhance existing advanced driver-assistance systems (ADAS). Some of the cornerstone technologies include GNSS and digital maps, which provide the accurate location for fully autonomous vehicles.

As was the case with the original DARPA challenge, spurring new innovations and socially beneficial products and services is a goal of the competition, Peak said. "In our case, we see inspiring teams' creation of software that can solve for edge cases — those problems or situations that occur only at an extreme operating parameter, such as avoiding unanticipated obstacles at high speeds while maintaining vehicular control," he said. "This applies not only for highly automated vehicles, but also for vehicles equipped with ADAS that aim to help human drivers avoid obstacles altogether. The notion is, if our university innovators can enable cars to outmaneuver others at 200 mph, they certainly can help enable you to avoid that piece of lumber that fell off the pickup in front of you on the 65-mph highway."

Photo: IMS

THE INDIANAPOLIS **Motor Speedway will be the site of the race.**

Peak said that a perfect place to demonstrate these technologies is the famous speedway, which for 100 years has tested automotive technology in a demanding environment. "Tackling automation at 200 mph in a race car is a bit more alluring than with a 20-mph people mover," he said.

In addition to ESN and Indianapolis Motor Speedway, other challenge partners include race-car manufacturer Dallara Automobili and the Clemson University International Center for Automotive Research (CU-ICAR).

$1.45 Million in Prize Money

During the final race at the speedway, teams will compete for $1 million as the first-place prize. Second- and third-place finishers receive $250,000 and $50,000, respectively.

The five-round competition starts with the submission of a white paper to demonstrate vehicle automation with a video of an existing vehicle or participation in Purdue University's self-driving go-kart competition at the speedway.

During the initial rounds, teams will use sponsor ANSYS' driving simulator to develop autonomous vehicle software. ANSYS, which will provide $150,000 in prizes to top finishers of a third-round race, will co-host a hackathon to let teams work with the simulator, the company said. The fourth round allows teams to test their vehicles at the speedway in advance of the final race.

So far, five universities have registered: Korea Advanced Institute of Science & Technology (KAIST), Texas A&M

Transportation Institute (TTI), University of Florida, University of Illinois and University of Virginia.

Not Everyone Has Championed Autonomous Vehicles...

The new competition is commencing during a time when media reports show that the once-hot autonomous vehicle industry has vocal critics. Recently, Apple pioneer Steve Wozniak, who once headed a GPS-based fleet company called Wheels of Zeus, said he didn't expect to see a fully autonomous vehicle operating on the streets in his lifetime.

In addition, a few automakers have reined in autonomous vehicle development or have scaled back their technology expectations in recent months.

"Not at all surprising. The traditional OEMs were never going to be disrupters that put driverless mobility-as-a-service cars out there. It isn't their business model, and it won't be," said Alain Kornhauser, Princeton University professor and transportation program director, who was head of the university's team during the DARPA Challenge, in his *Smart Driving Cars* weekly newsletter. "Self-driving, I dare say Level 2, is and has always been their sweet spot — it sells cars. Now watch these same companies throw monkey wrenches into those driverless mobility machines to protect their conventional business model."

Peak says the recent negative press on autonomous vehicles is what happens when any new technology is rolled out. "For any new technology, such as automation, we're going to see euphoric coverage (automation will solve all of our problems) and pessimistic coverage (automation will never arrive and, if it does, it will make things worse)," he said. "It's a cycle, it swings back and forth, and we happen to be touching upon the latter, pessimistic end of that cycle."

Taking a moderate and realistic position about the technology is what the Indy Autonomous Challenge is striving to do, Peak said. "Automated vehicle technologies have a role to play, both in helping humans drive better, and eventually in enabling new markets, such as first/last mile transit solutions. The technologies are light years ahead of where they were a decade ago, and low-level automated technologies are already making a difference and saving lives in today's vehicles," he said. "We have a bit of a ways to go before the full potential of automation will be realized, and the Indy Autonomous Challenge will help us address the concerns brought about by the media and others to reach this end goal much sooner than we otherwise would."

For more, go to **www.indyautonomouschallenge.com**.

①

②

③

④

⑤

1. GNSS SIMULATOR

TESTING FOR SIGNALS AND SENSORS

The GSG-8 is an advanced software-defined simulator that offers ultra-high performance and flexibility in an easy-to-use format. It was developed to deliver the highest standard of GNSS signal testing and sensor simulation performance in an upgradable, scalable platform. The GSG-8 uses the robust 1000-Hz Skydel software engine. It is designed for customers who require complex capabilities to validate product and program performance in harsh, high-risk environments where failure is not an option, such as government agencies, space programs and specialized commercial programs.
Orolia, www.orolia.com

2. GNSS MODULE

CM-LEVEL GNSS POSITIONING FOR IOT

The Edge Locate GNSS L1/L2/E5 module combines antenna, RF electronics and receiver technology to deliver reliable centimeter-level positioning for the internet of things (IoT). It provides 1- to 3-centimeter-level accuracy using multi-band GNSS technology. With Edge Locate, manufacturers can quickly and effectively build devices with centimeter-level positioning technology. Its multi-band GNSS positioning can be used in conjunction with real-time kinematic (RTK) positioning capability. It uses a common connector for integration into any electronics device. It also connects directly to the Taoglas Edge board for immediate connectivity options.
Taoglas, www.taoglas.com

3. PRECISION ANTENNA

OFFERS STRONG MULTIPATH REJECTION

The VSP600L VeroStar precision antenna supports the full GNSS spectrum, as well as L-band correction services, and provides low-elevation satellite tracking with a high-efficiency radiating element. It is suitable for real-time kinematic (RTK) and precise point positioning (PPP) applications, and features a light, compact and robust design. It also has a low axial ratio through all elevation angles, providing strong multipath rejection. The VSP600L VeroStar provides high receive gain over the full GNSS spectrum: low GNSS band (1164 MHz to 1300 MHz), L-band correction services (1539 MHz to 1559 MHz) and high GNSS band (1559 MHz to 1610 MHz).
Tallysman, www.tallysman.com

4. L1 + L5 CHIP

SUITABLE FOR IOT AND AUTO OBD

The ORG4600-B01, OriginGPS' first dual-frequency GNSS module, is supported by the BCM47758 chip, enabling ultra-accurate GNSS positioning. It was developed for solutions requiring super-precision GNSS and a dual-frequency combination. The module enables customers to build solutions with sub-1-meter accuracy without implementing external components. Measuring 10 x 10 millimeters, the ORG4600-B01 supports L1 + L5 GNSS reception with one RF port, enabling use of a low-cost, dual-band antenna delivering sub-1-meter accuracy performance in real-world conditions. An alternate build option allows for separate L1/L5 RF outputs when dual antennas are required. The module is suitable for solutions requiring ultra-accurate positioning, such as telematics, the internet of things (IoT) and auto OBD applications.
OriginGPS, origingps.com;
Broadcom, www.broadcom.com

5. OEM RECEIVER

ALL-CONSTELLATION, MULTI-FREQUENCY POSITIONING

The PwrPak7-E2 contains an advanced Epson G370N MEMS inertial measurement unit (IMU) to deliver NovAtel SPAN technology in an integrated, single-box solution. It has a powerful OEM7 GNSS engine, built-in Wi-Fi, onboard NTRIP client and server support, and 16 GB of internal storage with higher performance and INS data rate. Connection options include serial, USB, CAN and Ethernet. Features include a 555-channel, all-constellation, multi-frequency positioning solution and multi-channel L-band that supports TerraStar correction services. It can be paired with an external receiver to support ALIGN GNSS azimuth aiding for low dynamic applications.
NovAtel, www.novatel.com

emcore®

TRANSFORMING NAVIGATION

LAND | SEA | AIR | SPACE

SYSTRON DONNER INERTIAL
An EMCORE Company

- Most comprehensive tactical and navigational grade product suite available
- Fiber Optic and MEMS Gyroscopes, IMUs & INS
- Industry-leading performance and CSWaP

EMCORE, combined with the products of **Systron Donner Inertial**, is one of the largest inertial navigation providers in the industry, offering a broad, complementary suite of ITAR free solutions. EMCORE's single-axis FOGs and three-axis IMUs and INS, along with Systron Donner's world-leading quartz-based MEMS Gyros, Accelerometers, IMUs and GPS/INS products, deliver higher performance with lower Cost, Size, Weight, and Power (CSWaP) than competing products.

Our navigation solutions feature high bandwidth, high input rate and low noise combined with proprietary integrated optoelectronics which makes them ideal inertial navigation devices for UAVs, UUVs, manned aircraft and rotorcraft, missiles, guided bombs and torpedoes, weapons stabilization/targeting and man-portable warfighter applications.

EMCORE and Systron Donner Inertial are transforming navigation worldwide with leading-edge products, expert application support and technology guidance.

emcore®

CONTACT:

navigation-sales@emcore.com
+1 626 293 3700 or +1 866 234 4976
www.emcore.com/nav

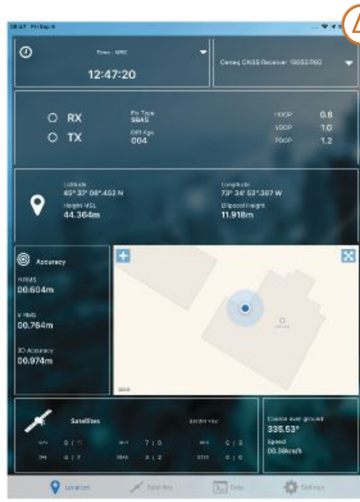
LAUNCHPAD | SURVEYING & MAPPING

①

②

③

④



1. GNSS SMARTPHONE

COLLECTS GEOSPATIAL DATA

The MobileMapper 60 is a durable, efficient and accurate handheld device for geographic information system (GIS) and professional data-collection applications. The all-in-one GNSS receiver and smartphone offers 2-4 meter positioning accuracy in an all-weather design with a hand strap. It operates in extreme temperatures and rugged field conditions. It features a 6-inch high-resolution screen, large capacity all-day battery, Android 8.0 operating system and 2.2-GHz processor. Its 4 GB of memory and 64 GB of storage can manage large data sets with ease and speed. Bluetooth 4.1, 4G LTE and Wi-Fi capable, the MobileMapper 60 is suitable for cadastral, survey, topography and forestry.
Spectra Geospatial, spectrageospatial.com

2. OUTDOOR AR

ENABLES VISUALIZATION OF 3D DATA

The SiteVision outdoor augmented reality (AR) system enables users to visualize 2D and 3D data with cellular or internet connectivity for planning, collaboration and reporting. Combining hardware and software in an integrated, lightweight handheld or pole-mounted solution, users can view 3D models and assets in a real-world environment at a 1:1 scale, from any angle or position. SiteVision integrates a Trimble Catalyst DA1 antenna, electronic distance measurement (EDM) rangefinder and power management into a lightweight, handheld device that connects to a user-supplied Android mobile phone. The SiteVision subscription is available monthly or yearly, and combines Trimble's high-accuracy positioning services and cloud-based processing technology to create a centimeter-accurate AR system. Users can visualize digital models from a wide range of data collection, design and constructible modeling tools in open industry-standard formats, including IFC and LandXML. For civil projects, SiteVision accurately visualizes data from Trimble's Quantm, Business Center and Novapoint; design data from Civil 3D and Bentley OpenRoads; and GIS data from Esri ArcGIS software.
Trimble, trimble.com

3. SMART ANTENNA

TRACKS ALL CHANNELS

The S621, powered by the Phantom 40 GNSS OEM board, is a redesign of Hemisphere's previous S321+. It processes and supports more than 800 channels with flexible and scalable simultaneous tracking of every modern and planned GNSS constellation and signal including GPS, GLONASS, BeiDou (including Phase 3), Galileo, QZSS, IRNSS, SBAS and Atlas L-band. The S621 combines Hemisphere's Athena GNSS engine and Atlas L-band correction technologies with a new web user interface. It meets IP67 requirements and is immune to magnetic interference. It is designed for use in land or marine survey, GIS, mapping, construction or other applications requiring high-performance precision and positioning.
Hemisphere GNSS, hemispheregnss.com

4. IOS APPLICATION

RECORDS AND TRANSFERS RAW DATA FOR POST PROCESSING

The SXblue ToolBox is now available for iOS-compatible devices. The application was developed with special interest paid to raw data recording and NTRIP service connection. The Android application debuted in 2018. With the new iOS application, iPhone and iPad users can analyze the position data provided by the SXblue receiver, as well as location metadata. The application can record, save and transfer raw data from the GNSS receiver, thereby allowing post-processing activities. The application also acts as an NTRIP client, capable of connecting to an NTRIP server for real-time kinematic (RTK) corrections, and thus allows the receiver to issue very accurate location information. Receiver configuration is easy through the application, with the ability to set up and save user-defined commands for subsequent use. The settings include constellation to be used, differential source, NTRIP login credentials list and more.
Geneq, sxbluegps.com

orolia
DEFENSE & SECURITY

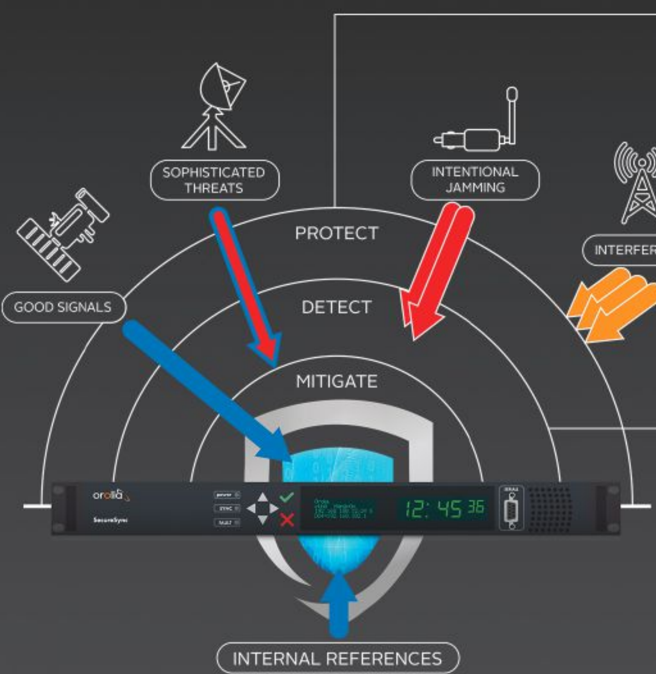
IDM

Interference Detection & Mitigation

Your most critical systems depend on GPS, vulnerable to threats such as jamming and spoofing which are at an all-time high. It is necessary to ensure the integrity of your assets, and fortify them with technology that can conform to new and emerging threats. You can rely on Orolia's IDM solutions knowing that our technology is regularly updated and has been rigorously tested and field-proven for over a decade, even earning a United States patent.

SecureSync + BroadShield

GPS SYNCHRONIZATION + INTERFERENCE MITIGATION



ThreatBlocker

GPS JAMMING + SPOOFING PROTECTION

BroadSense Nano

GPS JAMMING + SPOOFING AWARENESS

IDM SOLUTIONS → SALES@OROLIADS.COM | WWW.OROLIADS.COM/IDM

1. TELEMATICS FOR FORD

SIMPLIFIES MIXED-FLEET MANAGEMENT

The Geotab Integrated Solution for Ford Vehicles integrates Ford vehicle data into the MyGeotab platform to give fleet managers a dedicated portal to process data. Ford Data Services securely transfers data from Ford vehicles with a factory installed or plug-in modem to Geotab's cloud environment. It provides access to the Geotab Marketplace, a portfolio of mobile apps, hardware add-ons and software add-ins.

Geotab, www.geotab.com

2. POSITIONING PLATFORM

ENHANCED GNSS FOR AUTOS

The M9 platform is designed for demanding automotive, telematics and UAV applications. With the u-blox UBX-M9140 GNSS chip, the M9 technology platform and the NEO-M9N (the first module based on the platform) can receive signals from GPS, GLONASS, BeiDou and Galileo concurrently. It can achieve high positional accuracy in difficult conditions such as deep urban canyons. The M9 offers a position update rate of up to 25 Hz, enabling dynamic applications to receive position information with low latency and has special filtering against RF interference, jamming and spoofing. U-blox also provides Explorer Kit M9 (XPLR-M9) for developers.

u-blox, www.u-blox.com

3. GPS TRACKER

FOR LIGHT- TO MEDIUM-DUTY VEHICLES

The SA2012 GPS tracker is equipped with the latest 4G LTE with 3G fallback. It is designed for customers looking for a scalable vehicle telematics solution. The hardware can be installed using the SkyBitz Ops Center mobile device, either directly plugging it into the vehicle diagnostic port or covertly installing it behind the dashboard. Once installed, the device feeds into the Ops Center platform, where users can manage the new device and others via a single interface. Coverage is across North America.

SkyBitz, www.skybitz.com

1

2

3

LabSat

Compact yet powerful multi-constellation, multi-frequency GNSS testing solution.

Wide Bandwidth

Up to 56MHz bandwidth and 6-bit sampling

Multi-Frequency

Record and Replay in the upper and lower L Band

Multi-Constellation

Record and Replay RF signals from all GNSS constellations

Easy Configuration

HTML interface for convenient device set-up

RELIABLE • REPEATABLE • CONSISTENT

SatGen Software

Create custom simulations using all signals

Future Proof

Supports future full constellations such as L2C, L5 and L1C

Field Testing

Portable with up to two hours battery runtime for field testing

External Signals

Additional signals (RS232, CAN, Digital) synchronised to GNSS

Register now for your **FREE 14 DAY LabSat TRIAL** labsat.co.uk

ACCESS DENIED

BY MATTEO LUCCIO
CONTRIBUTING EDITOR

Anti-Jam Technology Mitigates Navigation Warfare Threats

GPS signals are by far the single most widely used and most accurate source of navigation, positioning and timing (PNT), and this capability is deeply integrated into every aspect of our society. In particular, the timing service provided by GPS, while virtually unknown to the general public, is essential for a variety of digital operations — from performing financial transactions to operating cell phone networks to running the internet.

Of course, GPS — originally developed to guide nuclear submarines — is now vital to most military missions, and the system's vulnerabilities are a source of great concern.

GPS has been remarkably reliable over the past quarter century. Solar flares are rare, multipath can be largely mitigated, and obstructed line-of-sight to the satellites is an acute problem only in certain environments, such as urban canyons.

The most serious intentional threats to GPS are spoofing and jamming. Jamming is more widespread — it is more easily accomplished intentionally and it also occurs unintentionally. In the defense sphere, intentional jamming is a regular occurrence. It is expected as a routine aspect of electronic warfare operations to disrupt and deceive, typically just before the shooting begins. Unintentional jamming includes recently re-emerging concern about potential interference by ultra-wideband devices.

Experts at NovAtel, Collins Aerospace, L3Harris Technologies and Honeywell address the challenges posed by jamming and the relative effectiveness of various anti-jamming approaches.

NOVATEL

Tackling Jamming on Multiple Levels

Disruption by jamming of GPS's PNT data "is occurring with a growing regularity," said Dean Kemp, Defense Segment manager at NovAtel, part of Hexagon's Positioning Intelligence division. The problem will only increase, given our reliance on GNSS and increasing demand for precision. In the military sphere, electronic warfare in Syria, as well as jamming in Ukraine, Korea, and Finland, "have shown that modern, high-power equipment is routinely being used to disrupt the military."

In the civilian sphere, interference is a growing issue because of cheap and effective jammers available via the internet. People use these so-called personal privacy devices to defeat vehicle tracking devices for purposes ranging from avoiding supervision all the way to hijacking vehicles.

GNSS signals are vulnerable because the received power is so small that receivers can be disabled with an incident power in the picowatt (10^{-12} W) range. "Jammers come in many different forms," Kemp said, "from low-power civil devices to complex and powerful military-grade electronic warfare systems that can disable civilian receivers from a few hundred meters to hundreds of kilometers."

Situational Awareness. Users can fail to recognize that their GPS is being jammed, Kemp said. Beyond defending against possible jamming scenarios, it is also necessary to "identify, find, and characterize the source of interference and to provide this information to the user so that it can be used appropriately." In the defense field, this is known as situational awareness.

Emerging jamming threats, Kemp explained, can be understood within the context of cyber and information warfare using the Cyber Electromagnetic Activities (CEMA) layered approach. It recognizes a cognitive layer — a human decision based on PNT data; a virtual layer, in which PNT data are used to inform or support networked systems; and a physical layer, the hardware used to provide and protect PNT data. Therefore, effective anti-jamming requires that:

- users understand the system's vulnerabilities and identify when they are being jammed, so that they can resort to traditional means for positioning and navigation (but not timing)
- PNT data be protected and verified before being trusted
- on the physical level, there be a multi-layered and heterogeneous approach that provides assured PNT information in the presence of jamming and spoofing without quantifiable loss of accuracy.

By combining these considerations at each layer, "they form a unified view on capability," Kemp said.

Spoofing with Pokémon. Jamming threats are evolving, employed by both civilian and state actors. Worse, these threats are augmented by spoofing. While spoofing is harder to achieve than jamming, it is potentially more concerning. "Spoofing the receiver by rebroadcasting the GNSS signals or by generating them from a simulator has become a regular occurrence," Kemp said.

Spoofing came to public attention in 2016 when enterprising programmers designed location-deception apps to hack the Pokémon Go mobile game. Instances have since been reported worldwide. Because early spoofing demonstrations were conducted against simple GPS L1 C/A-code receivers, it was initially hoped that spoofing could be defeated by using dual- or multi-frequency receivers.

However, it has been demonstrated that multi-frequency receivers using commercially available components can also be spoofed, "at least when the receiver is using multiple frequencies of GPS," Kemp noted. "Adding further GNSS signals will help, but the best defensive measure is to employ, if authorized, an encrypted military signal."

Coverage Improvement Factor. Typically, the effectiveness of an anti-jam system is assessed on the basis of the jamming to signal ratio (J/S) figure in decibels, which depends on variables such as the receiver's front-end RF bandwidth, the signal type being tracked (C/A versus P(Y) code), the signal tracking threshold of the receiver, the receiver platform dynamics, the choice of receiver oscillator, the interference type and antenna characteristics.

Difference in how manufacturers calculate J/S led to the invention of the coverage improvement factor (CIF), adopted by the GPS Joint Project Office. "CIF gives a single number that describes the effectiveness of an anti-jam system for a particular jammer scenario, given that space vehicle positions vary by elevation and azimuth," Kemp said. However, the use of CIF to assess the anti-jam performance is a highly technical process and the results are usually classified. He discussed current approaches to anti-jamming.

- Multi-element, controlled reception pattern antennas **(CRPA)**, which pass the good signal to the receiver while nulling out the interference, are the first line of defense. "The system can dynamically change the gain pattern of the antenna so that as the platform and jammers move, the gain pattern adapts so that nulling continues effectively."
- The use of **multiple constellations and frequencies** can be an effective tactic to mitigate interference, "but relies on the jammer not covering the bands of interest."
- "Obtaining **actionable data on interference** is almost as important as mitigation," because it enables users to modify plans. However, "interference effects can be difficult to diagnose and complicated to track down."
- Monitoring **automatic gain control** can indicate jamming.
- "Coupling a GNSS receiver with a robust **inertial measurement unit (IMU)** will provide a higher level of protection for GNSS signals due to the IMU providing reliable position, velocity and attitude even through short periods when satellite signals are blocked or unavailable." However, IMUs are liable to drift, resulting in degraded performance.

There are many approaches to designing anti-jam systems. They must be balanced against user requirements, which vary significantly. "A layered approach is the best form of defense against jamming and spoofing," Kemp said, starting with protecting the incoming GPS signal. "One of the highest levels of protection is from an anti-jam antenna system paired with a GNSS receiver that is tightly coupled with an IMU."

Finally, given that jamming attacks are now to be expected on the battlefield, it is critical to train users on the best response.

COLLINS AEROSPACE

A Potent Triumvirate of Tools

Photo: Collins Aerospace

DIGAR 100 GPS anti-jam receiver.

While sources of deliberate jamming are on the rise, the vast adoption of GPS means that "even the non-deliberate sources of jamming will have an asymmetric impact on end users," said Sai Kalyanaraman, Ph.D. and Technical Fellow at Collins Aerospace. Challenges posed by jamming depend on the receiver, mission and performance needs, while the source of unintentional jamming could be "something as simple as a TV antenna that is transmitting harmonics into the GNSS band."

Kalyanaraman outlined viable approaches to interference mitigation and anti-jamming:

- Integration with inertial navigation systems (INS) can provide the platform's attitude, which is required for beam forming. This, in turn, is required for some of the CRPA GNSS Anti-jam signal processing modes. It can also alert the user of jamming when the INS position diverges dramatically from that provided by the GPS receiver.
- Use of multiple frequencies is a form of robust design against interference.
- For authorized users, M-code will provide additional limited capabilities against jammers.
- Integration of GNSS with other PNT sensors to help address GNSS-denied environments.

GNSS signals have the advantage that the true signal is well under the noise floor; therefore, "as long as you can characterize the noise floor adequately from the receiver design/installation perspective, anything that shows up above the noise floor typically does not belong in that slice of the spectrum," Kalyanaraman said. Combining a CRPA, a platform orientation sensor (like an INS), and a GPS/GNSS receiver, "you have a fairly potent triumvirate of tools that you can use to help mitigate the impacts of jamming and potentially spoofing."

Collins produces multiple variants of its digital integrated GPS anti-jam receivers (DIGAR). "Depending on which variety you choose, you can essentially have a receive apparatus that can perform basic nulling all the way up to beam forming and direction finding and help provide resiliency against high jamming signal levels and other threats that emulate a GNSS-like signal in space," Kalyanaraman said.

L3HARRIS TECHNOLOGIES

Field Tests Verify PNT Reliability

Credit: U.S. Army/Spc. Robert Porter

L3HARRIS DEVELOPS gun-hardened anti-jam solutions for the M1156 Precision Guidance Kit Modernization program. The kit turns 155-mm artillery shells into smart weapons. Here, soldiers test the kit for accuracy.

Dealing with deliberate and unintentional interference with GPS requires agreeing on the level of enhancements required, reducing the time and cost needed to integrate them into systems of systems, and "centralizing PNT generation and distribution functions on a platform to reduce user equipment redundancies and increase the leverage of future PNT enhancements," said Dave Duggan, president of the Precision Engagement Sector at L3Harris Technologies.

The increase in interference "creates a cascading negative effect to PNT client mission systems," Duggan said, including the systems of systems for sensing, maneuver and fires [military-speak for the use of weapon systems]." The capability of anti-jam countermeasures "scales across a range of performance, size, weight, power and cost points and can be tailored to a given threat space, improving the performance of even legacy user equipment."

Spoofing, which inhibits receivers from forming a solution or, worse, tricks them into passing misleading PNT solutions to other systems, is a bigger challenge than jamming because it can result in aborted missions and loss of life and usually requires new receivers, Duggan said.

Duggan defines a reliable anti-jam/anti-spoof capability as one that "provides a PNT solution with a high level of confidence in its accuracy, authenticity and integrity for their applications and anticipated threat environments — all at a reasonable cost/performance point." Confidence in the solution requires "extensive analysis, threat modeling, simulation and testing of the anti-jam/anti-spoof capability." For this reason, "L3Harris has worked extensively in developing simulation and testing environments of the highest fidelity and continues to participate in numerous live field test events to establish that foundation."

L3Harris develops and produces digital anti-jam antenna electronics for U.S. and allied end use.

www.javad.com

Front

SPOOFING SUMMARY ...

As we explained on inside pages, in addition to the shape of spectrum and AGC, there are eight indicators that show the health status of GNSS signals:

The eight indicators for each signal are:

1. Number of signals tracked.

2. Diversion of SNR from its expected value.

3, 4. Level of additional power and its RMS.

5, 6. Diversion of AGC from its normal value and its RMS.

7. Extra noise.

8. Number of signals spoofed.

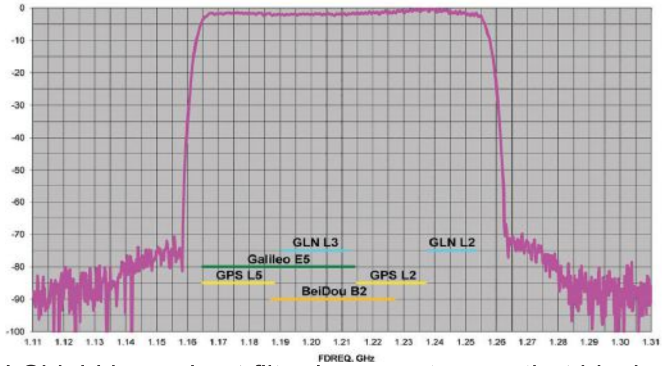
The figure on the top right is a compact view of status of all GNSS signals in our TRIUMPH-LS receiver, showing **normalized** values of the above eight indicators. “0” means “good” and “9” means “bad”.

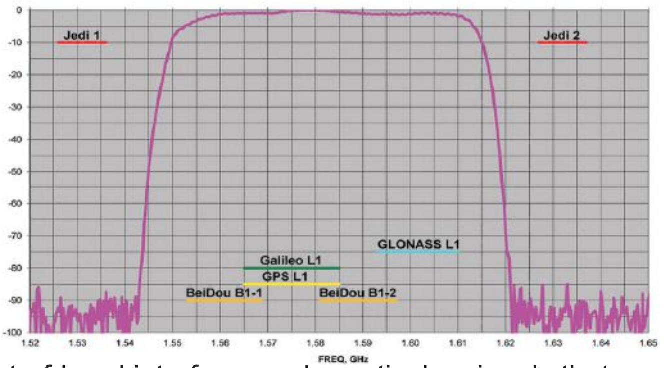
The figure below it shows the normalized **weighted average** of the above indicators. It is to show a general view of the status of that band at a glance.

Click on any of the signal buttons to see the actual and normalized values of the eight indicators for that signal.

Click on the action buttons shown to see:
Details of all signals,
View Spoofing details,
View Spectrum screens,
and take new spectrum.

J-Shield Filters
and Near Band Interference



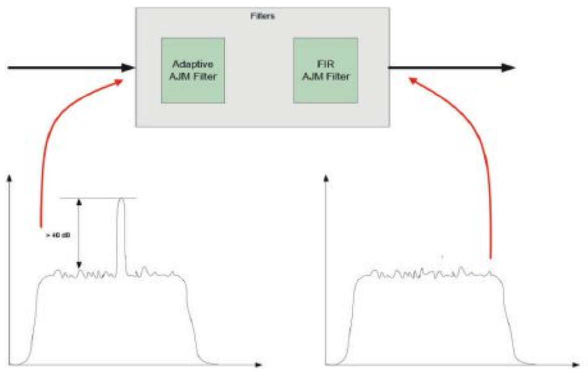


J-Shield is a robust filter in our antennas that blocks out-of-band interference. In particular signals that are near the GNSS bands like the LightSquared signals. The above graphs show the protection characteristics of our J-Shield filters. They are sharp 10dB/KHz skirt which provide up to 100 dB of protection. It makes the precious near band spectrums available for other usages and protects GNSS bands now and in the future.

Antijam Digital Filters

We have sixteen 255th order FIR antijam digital filters to protect against **static** in-band interference, like harmonics of TV and radio stations, or against illegitimate in-band transmissions.

Also we have sixteen adaptive 80th-order digital filters to protect against **dynamic** interference. These AJM-filters can be combined in pairs for complex signal processing. These filters can simultaneously suppress several interference signals.



In-Band noise
Measurement

We measure the level of interference as percentage of noise above the normal condition. The above left screenshot shows the condition in a clean environment. 8 GPS satellites were visible (according to the almanac). 8 C/A, 6 P1, 6 P2, 6 L2C and 2 L5 GPS signals were tracked. The noise level is 2% on C/A and L5, and 0% on P1,P2,and L2C. The screenshot on the right shows 290% noise in GPS C/A and %121 on Galileo E1. Only one of 8 GPS C/A code and none of 5 Galileo E1 signals were tracked due to this level of interference.

Spectrum Shape

We have a very powerful spectrum analyzer within our GNSS TRIUMPH chip. Each spectrum shows the power and the shape of the interfering signals and jammers. This is more powerful and more efficient than a $30,000 commercial spectrum analyzer to evaluate the environment. The screenshot on the right shows the shape of the GPS L1 band spectrum when the band is not jammed. The GPS C/A code peak at the 2-MHz center of the L1 band is visible. The height of the spectrum is 11.2 dB.

This is an example of GPS L1 spectrum with a commercial $30,000 spectrum analyzer.

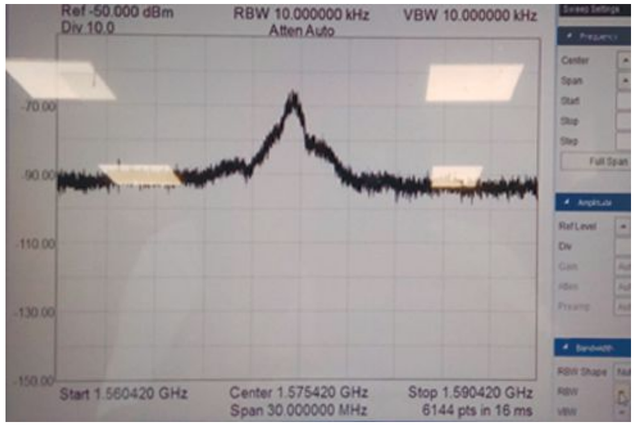
Our integrated spectrum analyzer has the advantage that it monitors the spectrum inside the chip where it matters. It has effective bandwidth of 1 KHz.

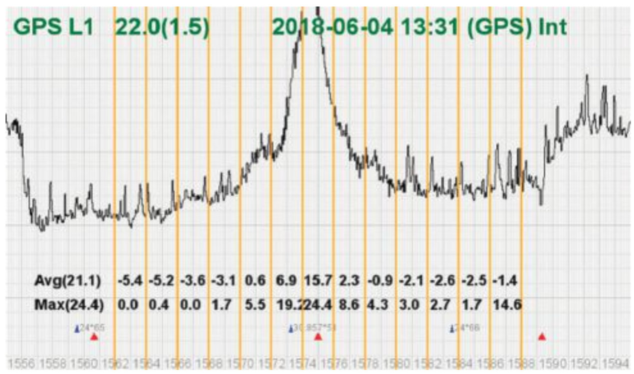
Our embedded spectrum analyzer also has the advantage that it can be programmed to automatically record the spectrum (and other information) periodically or according to the set conditions, and monitor the environment continuously.

This is the spectrum example of a GPS L1 band when it is jammed. There is a huge peak in the center where the C/A code is. The number on the bottom left is the height of the peak.

The height of the spectrum is 21.1 dB, which compared to the calm 11.2 dB, indicates about 10dB of jammer.

Average energy and its RMS are shown in the graphs.





AGC

Automatic Gain Control

In addition to the spectrum, we also keep record of Automatic Gain Control which is another indicator of external signals.

The AGC monitors the environment and adjusts the gain to keep the voltage at a certain level. The change in AGC is an indicator of interference.

The narrow orange line in the middle of the band in this screenshot shows a quiet AGC. Average AGC and its RMS are shown in the top left of the graphs.

AGC in the second screenshot shows there are activities in this band which our AGC was able to defend against it.

Our AGC mitigates the effect of such interference completely.

Spoofers & 2 Peaks

Spoofers are quite different from jammers. They don't disturb the environment and the spectrum shape. They broadcast a GNSS-like signal to fool the GNSS receivers to calculate wrong positions.

We detect spoofers by digital signal processing. With 864 channels and about 130,000 Quick Acquisition Channels in our TRIUMPH chip, we have resources to assign more than one channel to each satellite to find ALL signals that are transmitted with that GNSS PRN code.

If we detect more than one reasonable and consistent correlation peak for any PRN code, we know that we are being spoofed and can identify the spoofer signals. Figure on the right is an example of two peaks. We isolate and ignore the wrong peak.

The screenshot on the right shows details of each signal peaks. The first six lines in this screenshot show the spoofed signals that we detected as soon as they appeared (numbers "1" in those line). The two section columns represents the characteristics of each peak. Second SS column show if the second peak is a consistent signal.

While six satellites were spoofed, there was no indication on the noise level (0%) and no indication on the spectrum shape and level as shown on the screenshot on the right below the chart.

If the spoofer strategy is to cover the real satellite signal and then put the fake signal on top of it to produce only one peak, we notice that by more that 200% of noise level that it has to introduce.

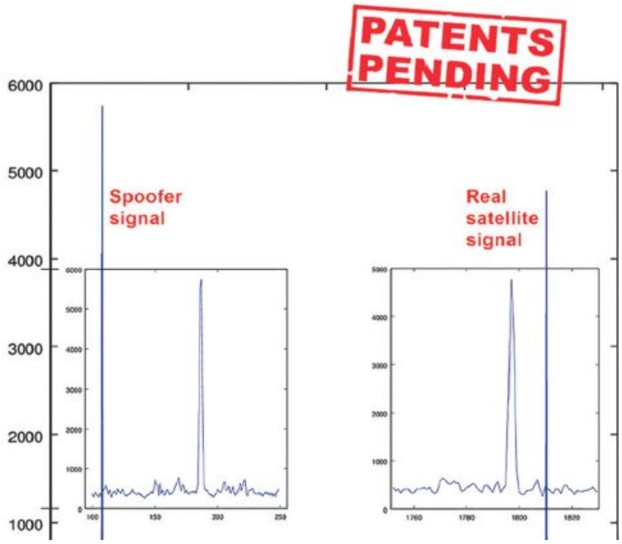
We reject infected signals and then among all the available GPS, GLONASS, Galileo, BeiDou, IRNSS and QZSS multiple signals we use the healthy ones.

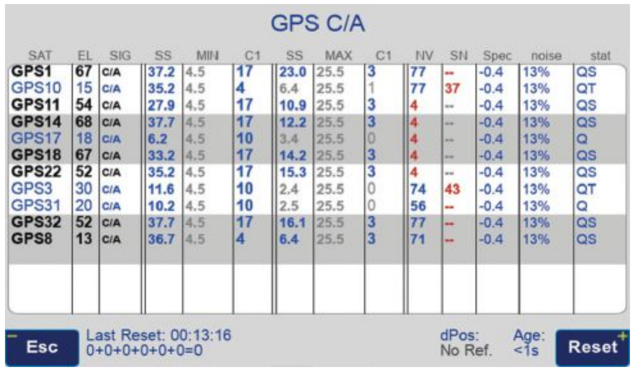
Usually there are over 100 signals available at any given time, and we need only four good signals to compute position. In rare cases that all signals are affected, we inform the user and guide them to use compass and altimeter to get out of the Jammed area.

It is extremely unlikely that we can be spoofed without our knowledge. We will immediately recognize and take corrective actions

In the Spoofing Summary screenshots on the right, 10 GPS satellites were visible (according to the Almanac). 6 of the 9 GPS satellites that we tracked were spoofed, as indicated by the red number, while the noise level was 0% in the GPS C/A band.

In the second screenshot, 5 of the 6 GPS C/A signals were spoofed while the noise in the band was only 2%.




GPS C/A

SAT	EL	SIG	SS	MIN	C1	SS	MAX	C1	NV	SN	Spec	noise	stat
GPS1	67	C/A	37.2	4.5	17	23.0	25.5	3	77	--	-0.4	13%	QS
GPS10	15	C/A	35.2	4.5	4	6.4	25.5	1	77	37	-0.4	13%	QT
GPS11	54	C/A	27.9	4.5	17	10.9	25.5	3	4	--	-0.4	13%	QS
GPS14	68	C/A	37.7	4.5	17	12.2	25.5	3	4	--	-0.4	13%	QS
GPS17	18	C/A	6.2	4.5	10	3.4	25.5	0	4	--	-0.4	13%	Q
GPS18	67	C/A	33.2	4.5	17	14.2	25.5	3	4	--	-0.4	13%	QS
GPS22	52	C/A	35.2	4.5	17	15.3	25.5	3	4	--	-0.4	13%	QS
GPS3	30	C/A	11.6	4.5	10	2.4	25.5	0	74	43	-0.4	13%	QT
GPS31	20	C/A	10.2	4.5	10	2.5	25.5	0	56	--	-0.4	13%	Q
GPS32	52	C/A	37.7	4.5	17	16.1	25.5	3	77	--	-0.4	13%	QS
GPS8	13	C/A	36.7	4.5	4	6.4	25.5	3	71	--	-0.4	13%	QS

Esc Last Reset: 00:13:16 0+0+0+0+0+0=0 dPos: No Ref. Age: <1s Reset

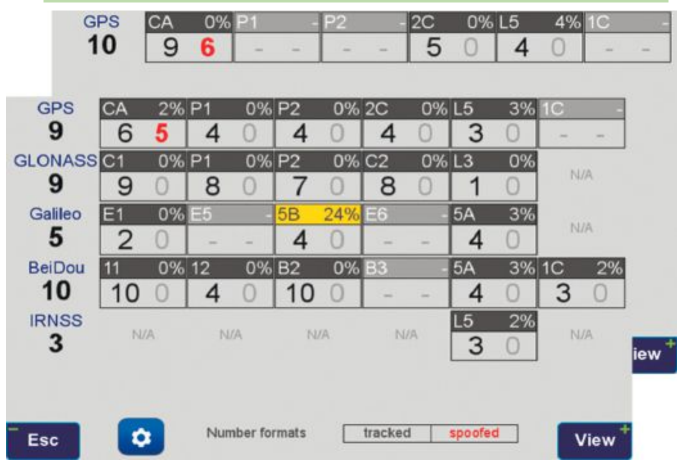
This above screenshot shows details of each signal. In the last column (T) indicates the signal was tracked by the main channels, (Q) by the Fast Acquisition Channels and (U) signal was used in position calculations.

Percentage numbers show the percentage of interference above the normal level.

In the above example seven GPS signals are spoofed.

The "SN" color coded column shows the signal-to-noise ratio of tracked signals. Blue is perfect, green is 3 dB down, and red is 6 or more dB down.

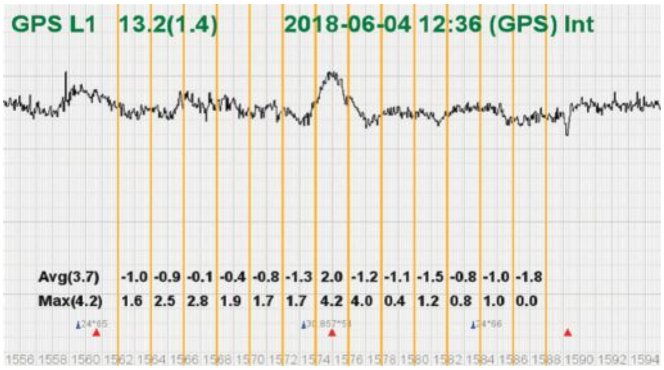
Deviation of SNR from the expected value is another important indicator of interference

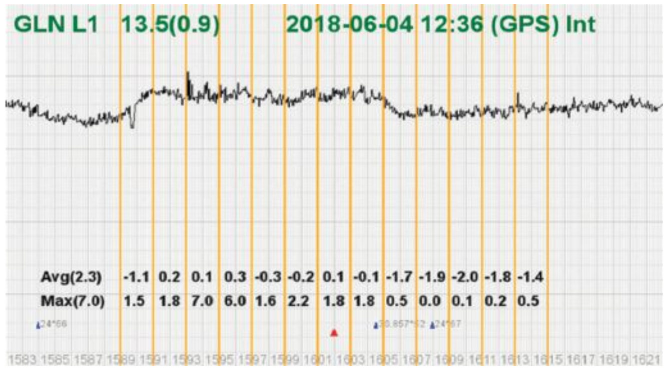


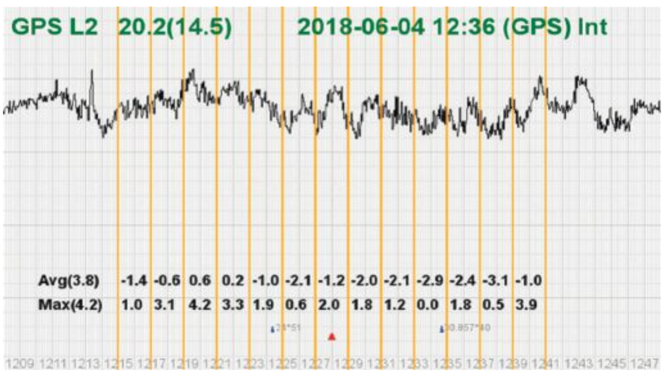
And Examples of when the world is peaceful.

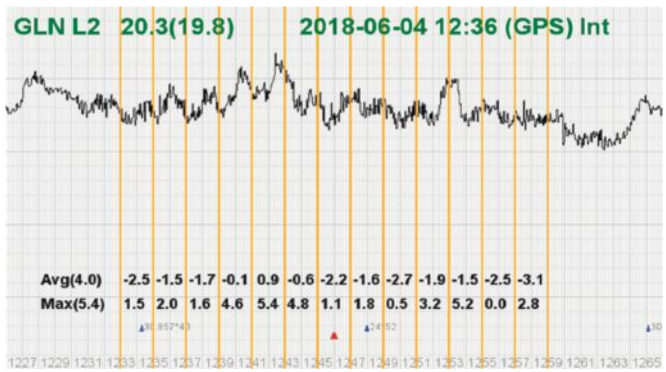
Jamming and Spoofing protection option is available in all of our products and OEM Boards.

All screenshots are from our TRIUMPH-LS Receiver.



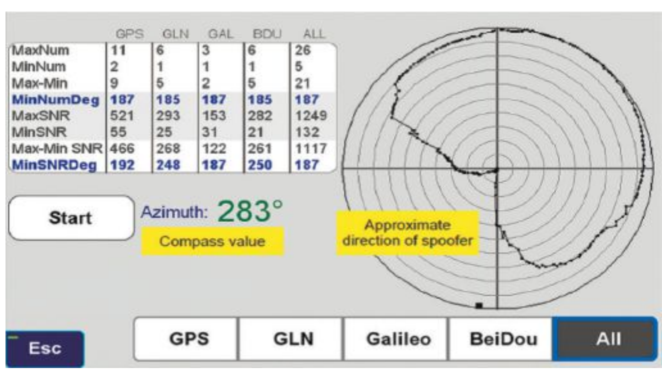




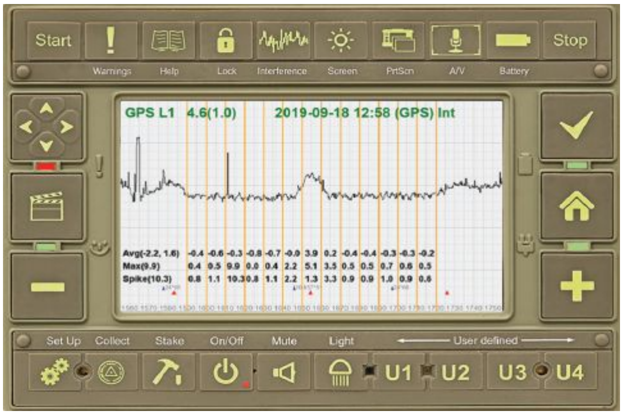


When you detect that spoofers exist, you can also try to find the direction that the spoofing signals are coming from. For this, hold your receiver antenna (e.g. TRIUMPH-LS) horizontally and rotate it slowly (one rotation about 30 seconds) as shown in the picture and find the direction that the satellite energies become minimum. This is the orientation that the spoofer is behind the null point of the antenna reception pattern.

After one or more full rotations observe the resulting graph that shows approximate orientation of the spoofer as shown in figure below.



... and TRIUMPH-LS



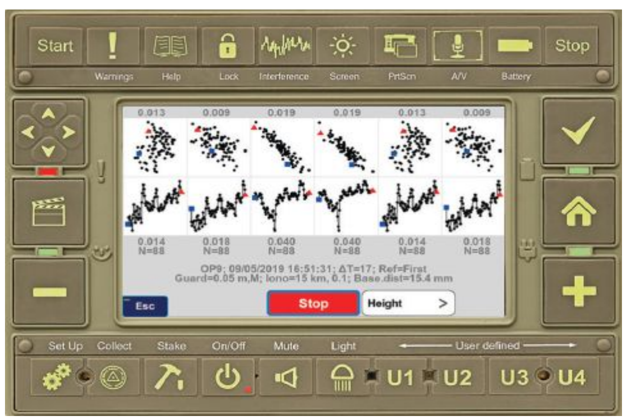
30 MHz-wide spectrum of the signal.

Two-peak information and spoofer.

Noise and spoofed signals.

Six parallel RTK engines.

Status of RTK survey collection.



Horizontal and vertical result of each engine.

TRIUMPH-3

The new TRIUMPH-3 receiver inherits the best features of our famous TRIUMPH-1M.

Based on our new third generation TRIUMPH chip enclosed in a rugged magnesium alloy housing.

The TRIUMPH-3 receiver can operate as a portable base station for Real-time Kinematic (RTK) applications or as a receiver for post-processing, and as a scientific station collecting information for individual studies, such as ionosphere monitoring and the like.

It includes options for all of the software and hardware features required to perform a wide variety of tasks.

- UHF/Spread Spectrum Radio
- 4G/LTE module
- Wi-Fi 5 GHz and 2.4 GHz (802.11 a, b, g, n, d, e, i)
- Dual-mode Bluetooth and Bluetooth LE
- Full-duplex 10BASE-T/100Base-TX Ethernet port
- High Speed USB 2.0 Host (480 Mbps)
- High Speed USB 2.0 Device (480 Mbps)
- High Capacity microSD Card (microSDHC) up to 128GB Class 10;
- “Lift & Tilt”
- J-Mobile interface

Ideal as a base station

HONEYWELL

Integrating GNSS with Inertial

Photo: Honeywell

HONEWELL'S HGUIDE micro-electro-mechanical system (MEMS) inertial measurement units (IMUs) and INS are designed to be integrated with GNSS receivers.

Heightened awareness of intentional and inadvertent jamming threats has less to do with new types of threats and more to do with the increased importance of precise PNT coupled with more frequent instances of jamming, according to Chris Lund, senior director, HGuide Navigation and Sensors at Honeywell Aerospace.

"As applications become more reliant on highly accurate and reliable position and timing information provided by navigation systems, the consequences associated with the data not being available or not being correct quickly escalate," Lund said.

The best way to measure the impact of a jamming threat and the capabilities of countermeasures is "to determine in actual real-world use cases whether the desired application outcome can still successfully be achieved," Lund said.

The most promising approach to anti-jamming is integration of GNSS receivers with inertial navigation systems (INS) and other PNT systems. "Given the complementary aspects of many of the available approaches in the anti-jamming toolkit, it's often best to leverage however many tools are available and needed to allow the application to achieve its desired outcome," Lund said.

New CRPA Concept Antenna Designed

BY Tony Murfin

GPS WORLD PROFESSIONAL OEM CONTRIBUTING EDITOR

In today's world where local conflicts can spill over into many other places, it's become common to encounter GPS signal jamming. Even in locations that defense forces might have considered "backwater" in terms of technology, enemies can apparently launch attack drones, jam adjacent countries, and generally render GPS, if not GNSS, useless for navigation.

The U.S. military came up with anti-jam technology to counter foreseen jamming scenarios several decades ago, but the initial seven-element controlled radiation pattern antenna (CRPA) designs were bulky and required multiple RF antenna cable connections to large, remote receiver processor units. These units not only processed the signals to derive position, but also eliminated jammer and satellite signals in the direction from which the jamming signal was received (null processing). Most of these early units were large and power hungry, so their application was limited to larger aircraft and ships.

Anti-jam technology has gradually evolved over time. Component integration and miniaturization has enabled CRPA performance to be self-contained within the antenna enclosure. At least one design has now migrated the null-processing into the same enclosure as the CRPA antenna, and is sold on a commercial basis to several military forces around the world. The device outputs a single composite RF signal that has been cleaned of any detected jamming signals for use by both commercial and military remote receivers alike.

Now Quantum Reversal (QR) — a new company based in Calgary, Alberta, Canada — has come up with a novel design that processes the CRPA signal in the RF domain, eliminating the need for extensive null-processing electronics. Without these signal-processing electronics, power requirements are reduced from about 15–30 watts to around 1 watt, the size is smaller (4 inches in diameter versus the nominal 6–8 inches in diameter), and cost is significantly lower. These reductions might allow

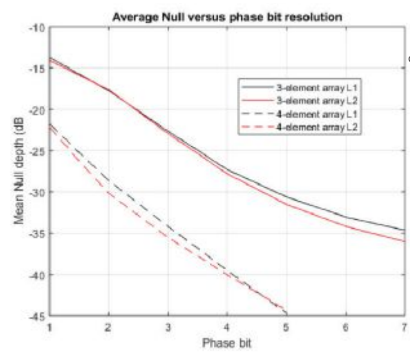


Image: Quantum Reversal

INCREASING THE NUMBER of antenna elements of the QR design improves the null depth (on average 8–10 dB per antenna element) at the expense of increased circuit complexity, power consumption and antenna size. An average null depth of –70 dB may be possible with a seven-element CRPA antenna.

this new anti-jam technology to move into small unmanned aerial vehicle (UAV) applications, timing networks, and reference monitoring networks where continuous uninterrupted GPS/GNSS service is mandatory.

This antenna is designed to enable continuous navigation using GPS or GNSS signals in the presence of unintentional low- to medium-power interference signals. It should be able to reduce the power of an unintentional interference or jamming signal by 35–45 dB, depending on whether it contains three or four CRPA antenna elements.

JAVAD GNSS

The Triumph-LS receiver.

Photo: JAVAD GNSS

J-Shield Filters out Interference

J-Shield is a robust filter on JAVAD GNSS antennas that blocks out-of-band interference (**FIGURE 1**). In particular, J-Shield blocks signals that are near the GNSS bands, including the proposed Ligado Networks (formerly LightSquared) broadband signals, explained Javad Ashjaee, founder and CEO of Javad GNSS.

The anti-jam digital filters protect against in-band interference such as the harmonics of nearby TV and radio stations, or against illegitimate in-band transmissions. The anti-jam filters can be combined in pairs for complex signal processing and can simultaneously suppress several interference signals.

"The filters make the near band spectrums available for other uses," Ashjaee said. "They protect GNSS bands now and in the future."

In-Band Noise Measurement. The receiver measures the level of interference as a percentage of noise above the normal condition. **FIGURE 2** shows the condition in a clean environment, where eight GPS satellites were visible, according to the almanac. In all, eight C/A, six P1, six P2, six L2C and two L5 GPS signals were tracked. The noise level was 2% on C/A and L5 and 0% on P1, P2, and L2C.

FIGURE 3 shows 290% noise in the GPS C/A signal and 121% noise in Galileo E1. Only one of the eight GPS C/A code and none of five Galileo E1 signals could be tracked because of the high level of interference.

Spectrum Analyzer

Filters in the GNSS antenna provide one way to protect GNSS signals from interference. Another is the receiver chip itself. For instance, the Javad GNSS Triumph chip includes an integrated spectrum analyzer — a more efficient solution than using a commercial spectrum analyzer to continuously monitor and evaluate the environment, Ashjaee explained.

The spectrum analyzer monitors the spectrum inside the chip. It has an effective bandwidth of 1 KHz, and can be programmed to automatically record the spectrum (and other information) periodically or according to pre-set conditions. Each spectrum shows the power and shape of any interfering signals and jammers.

FIGURE 4 shows the shape of the GPS L1 band spectrum when the band is jammed, as indicated by the huge peak in the center where the C/A code is. The number on the bottom left is the height of the peak. The height of the spectrum is 21.1 dB; compared to a calm spectrum of 11.2 dB, this spectrum indicates a jamming impact

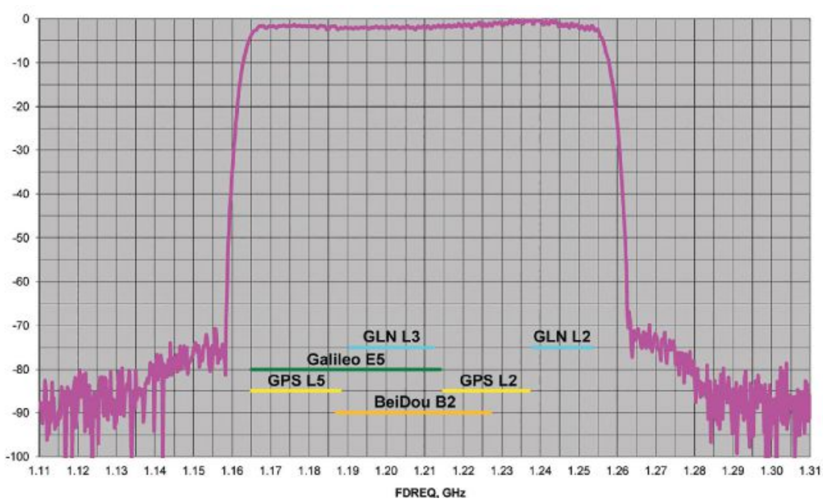


FIGURE 1. Protection characteristics: The J-Shield filters have a sharp 10-dB/KHz skirt, which provides up to 100-dB of protection.

FIGURE 2. Clean environment.

FIGURE 3. High interference levels.

All figures: Javad GNSS

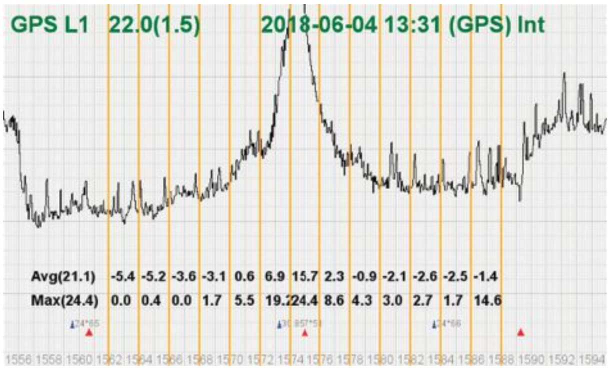
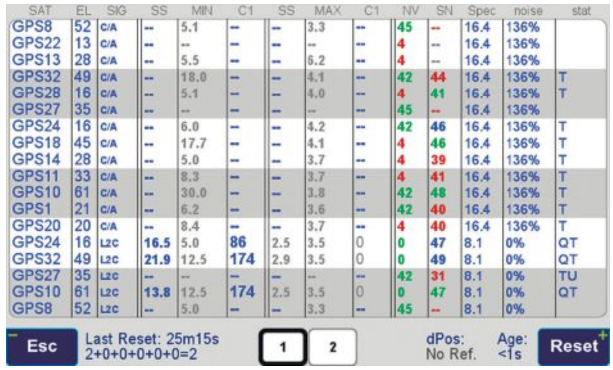


FIGURE 4. **The L1 band is jammed, as shown by the peak.**



SAT	EL	SIG	SS	MIN	C1	SS	MAX	C1	NV	SN	Spec	noise	stat
GPS8	52	C/A	--	5.1	--	--	3.3	--	45	--	16.4	136%	
GPS22	13	C/A	--	--	--	--	--	--	4	--	16.4	136%	
GPS13	28	C/A	--	5.5	--	--	6.2	--	4	--	16.4	136%	
GPS32	49	C/A	--	18.0	--	--	4.1	--	42	44	16.4	136%	T
GPS28	16	C/A	--	5.1	--	--	4.0	--	4	41	16.4	136%	T
GPS27	35	C/A	--	--	--	--	--	--	45	--	16.4	136%	
GPS24	16	C/A	--	6.0	--	--	4.2	--	42	46	16.4	136%	T
GPS18	45	C/A	--	17.7	--	--	4.1	--	4	46	16.4	136%	T
GPS14	28	C/A	--	5.0	--	--	3.7	--	4	39	16.4	136%	T
GPS11	33	C/A	--	8.3	--	--	3.7	--	4	41	16.4	136%	T
GPS10	61	C/A	--	30.0	--	--	3.8	--	42	48	16.4	136%	T
GPS1	21	C/A	--	6.2	--	--	3.6	--	42	40	16.4	136%	T
GPS20	20	C/A	--	8.4	--	--	3.7	--	4	40	16.4	136%	T
GPS24	16	L2C	16.5	5.0	86	2.5	3.5	0	0	47	8.1	0%	QT
GPS32	49	L2C	21.9	12.5	174	2.9	3.5	0	0	49	8.1	0%	QT
GPS27	35	L2C	--	--	--	--	--	--	42	31	8.1	0%	TU
GPS10	61	L2C	13.8	12.5	174	2.5	3.5	0	0	47	8.1	0%	QT
GPS8	52	L2C	--	5.0	--	--	3.3	--	45	--	8.1	0%	

FIGURE 5. **Signal Details: The Triumph-LS receiver provides users with a wealth of information on each signal received, including spoofed signals.**

of about 10 dB.

Automatic Gain Control. In addition to monitoring the spectrum, the Triumph chip also keeps a record of automatic gain control (AGC) — another indicator of unwanted external signals. The AGC monitors the environment and adjusts the gain to keep the voltage at a certain level. The change in AGC is an indicator of interference.

Spoofers

"Spoofers are quite different from jammers," Ashjaee said. "They don't disturb the environment and the spectrum shape. They broadcast a GNSS-like signal to fool the GNSS receivers to calculate wrong positions. We detect spoofers by digital signal processing."

With 864 channels and about 130,000 fast-acquisition channels in the Triumph 2 chip, it has the resources to assign more than one channel to each satellite to find all of the signals transmitted with the same GNSS PRN code — including spoofed signals.

"If we detect more than one reasonable and consistent correlation peak for any PRN code, we know that we are being spoofed and can identify the spoofer signals," Ashjaee said. The chip isolates and ignores the wrong peak.

"Usually more than 100 signals are available at any given time. We need only four good signals to compute position," Ashjaee said. "We reject infected signals, and then among all the available GPS, GLONASS, Galileo, BeiDou, IRNSS and QZSS signals, we use the healthy ones. It is extremely unlikely that we can be spoofed without our knowledge. We can immediately recognize spoofing and take corrective actions. In the rare case that all signals are affected, we inform the user and guide them to use a compass and altimeter to get out of the jammed area."

FIGURE 5 is a screenshot from the company's Triumph-LS survey receiver, showing the details of each signal tracked. The first six lines in this screenshot show the spoofed signals that were detected as soon as they appeared (number "1" in the C1 column). Percentages show the amount of interference above the normal level.

In the last column, T indicates the signal was tracked by the main channels, Q by the fast-acquisition channels, and U indicates the signal was used in position calculations.

Indicators for Healthy Signals

In addition to the spectrum shape and AGC, these other indicators show the health of GNSS signals:

- Number of signals tracked.
- Divergence of SNR from its expected value.
- Level of additional power and its RMS.
- Divergence of AGC from its normal value and its RMS.
- Extra noise.
- Number of signals spoofed.

As an aid to users, the company's Triumph-LS receiver can display the status of all GNSS signals received. **FIGURE 6** shows this compact view, with normalized values of the above indicators (0 means good and 9 means poor).

Users of the Triumph-LS can click on any of the signal buttons to see the actual and normalized values of the indicators for that signal. Action buttons provide quick access to View Satellites, View Spoofing, View Spectrum and Take Spectrum. Jamming and spoofing protection is an option on all Javad GNSS products and OEM boards.

FIGURE 6. **Signal Status. Information on all GNSS signals received as shown by the Triumph-LS.**

OEM

UAS1 Board Provides High-Precision GNSS to UAVs

The new Trimble UAS1 compact, high-precision GNSS board was specifically designed for unmanned aerial systems (UAS). Its simple connectivity and configuration allow UAS system integrators to add GNSS-based positioning — with the ability to upgrade its capabilities — using rugged connectors and Trimble's software interface, the company said.

Photo: Trimble

The board incorporates Trimble Maxwell technology. Its 336-channel GNSS engine is capable of tracking L1/L2 frequencies from GPS, GLONASS, Galileo and BeiDou for centimeter-level, real-time kinematic (RTK) positioning.

The compact board includes a broad range of receiver capabilities — from high-accuracy GPS-only to full GNSS features for positioning. Firmware options and features are password upgradeable, allowing functionality to be added as requirements change.

The receiver supports fault detection and exclusion (FDE) and receiver autonomous integrity monitoring (RAIM). System integrators also have the ability to detect interference with an RF spectrum monitoring and analysis tool embedded in the receiver.

The Trimble UAS1 has a Remote Network Driver Interface Specification (RNDIS) that enables manufacturers to access the web user interface with the USB connector. As with similar Trimble embedded boards and modules, software commands can simplify integration and reduce development times.

UAS1 FEATURES

- 71 x 46 x 13 millimeters; 45 grams
- Compact design for UAV/UAS applications
- Rugged latched connector for I/O
- Industry-standard camera hotshoe circuit
- CAN bus integrated
- LED indicators for status checks
- Trimble RTX and OmniSTAR Support
- EMI shielded GNSS module
- Centimeter-level position accuracy
- Advanced RF spectrum monitoring
- Outputs to RINEX
- Data-logging enabled
- Flexible interfacing over RS232 and USB

NavCom Releases Upgradeable OEM Board

NavCom Technology has released the Onyx multi-frequency GNSS OEM board. Offering integrated StarFire/RTK GNSS capabilities, Onyx features 255-channel tracking, including multi-constellation support for GPS, GLONASS, BeiDou and Galileo.

It also provides high performance in GNSS receiver sensitivity and signal tracking as well as patented multipath mitigation, interference rejection and anti-jamming capabilities.

The Onyx board is a fully upgradeable GNSS receiver. Through software optioning alone, it allows upgrades from free differential GPS signal sources such as WAAS, to increased accuracy services such as StarFire and RTK Extend. The software-enabled features are sold in bundles, but can also be purchased individually to suit changing application needs.

Photo: NavCom

Integrated StarFire is activated via an over-the-air licensing system that sends a StarFire license via satellite directly to the StarFire-capable receiver from NavCom's StarFire operations center.

StarFire, NavCom's global satellite-based augmentation system (SBAS), provides real-time global 5-centimeter accuracy without a base station. RTK Extend provides continuous RTK positioning during radio outages.

SURVEYING

Geneq Launches SXPad 1500 Rugged Data Collector

Photo: Geneq

The SXPad 1500 is designed for data collection for land surveying and geospatial information systems (GIS).

Geneq Inc. has added a new data collector to its SXPad product line. The rugged SXPad 1500 data collector features a full alphanumeric QWERTY keypad and long-range Bluetooth, and was designed to meet the rigorous IP67 standard to deal with challenging field conditions.

The SXPad 1500 and its 5-inch sunlight-readable touchscreen can be connected to any GNSS receiver or compatible robotic total station to ensure the success of all survey projects.

Driven by a 1-GHz processor and the Windows Mobile 6.5 operating system, the field collector is a high-performance device designed to provide the power needed to work with maps and large data sets in the field, as well as many software solutions.

With its integrated cellular modem and Wi-Fi standard, the SXPad 1500 offers wireless connectivity for internet access and GIS data transfer. This feature will be helpful for setting parameters and configuring the SXblue Premier and F90 or any real-time kinematic (RTK)-compatible GNSS receiver.

The SXPad 1500 has a GNSS internal module that delivers adequate performance for certain GIS field data collections.

Equipped with an internal memory of 1 GB (memory can be expanded to 16 GB with an SD card), the SXPad 1500 provides enough storage space for data recording.

Its high-performance lithium battery allows uninterrupted field operation for up to eight hours.

CHC Navigation Offers New GNSS RTK Tablet

CHC Navigation has announced the availability of the LT700H RTK Android tablet designed to increase the efficiency and productivity of mobile field workforces in any applications requiring centimeter to decimeter positioning accuracy.

Portable, rugged and versatile, the LT700H enables precision geographic information system (GIS) data collection, forensic mapping, construction site layout, environmental surveys, landscaping and earthmoving jobs.

Powered by a 184-channel high-performance GPS, GLONASS, Galileo and BeiDou module and a superior tracking GNSS helical antenna, the LT700H provides position availability in demanding environments. Its integrated 4G modem ensures seamless communication from field-to-office and robust connectivity to GNSS real-time kinematic (RTK) network corrections.

Photo: CHC Navigation

The LT700H RTK tablet is designed for mobile applications requiring high-portability. It enables use of GNSS technology by a single operator or by companies with large field crews.

Combined with CHCNAV Landstar 7 field data-collection software, the LT700H has an 8-inch in-plane switching (IPS) sunlight-viewable screen that clearly and sharply displays GIS data tables, vector and raster maps, and high-resolution pictures.

The tablet's Google Mobile Services (GMS) certification guarantees compatibility with any common GIS and mapping Android applications.

TRANSPORTATION

Photo: Neuwland Photography/Shutterstock.com

WAAS Upgraded with GEO 6 Payload

The Wide Area Augmentation System (WAAS) GEO 6 payload is now operational and fully integrated into the WAAS network, working with two other WAAS satellite payloads already in orbit to broadcast the WAAS message.

Raytheon provided the GEO 6 payload to the U.S. Federal Aviation Administration (FAA). The SES-15 satellite hosting the WAAS GEO 6 payload was launched in 2017 and completed extensive system integration in July. GEO 6 replaces an older WAAS geostationary satellite that had reached its end-of-service life.

WAAS increases GPS satellite signal accuracy for aircraft precision approach at 200 feet altitude to meet strict air navigation performance and safety requirements.

ADS-B Out Compliance Delayed in Canada

Canada is delaying the implementation dates for Phases 1 and 2 of its ADS-B Out Performance Requirements Mandate. Deadline for aircraft in the United States to be equipped with Automatic Dependent Surveillance – Broadcast (ADS-B) Out capability is Jan. 1, 2020.

The original deadline for implementation in Canada was set for Feb. 25, 2021, for Phase 1-Class A airspace and Class E airspace above FL600, and Jan. 27, 2022 (Phase 2-Class B airspace). Because numerous industry operators have stated they will not be able to meet those deadlines, new Phase 1 and 2 implementation dates will be set.

VW Golf in Europe Has NXP'S Secure V2X

Photo: Volkswagen

The new Volkswagen Golf, Series 8, will come equipped with RoadLINK V2X (vehicle to everything) communications from NXP Semiconductors. This makes the VW the first volume European car model equipped with V2X.

The NXP technology can prevent accidents by having cars communicate with each other, independent of car brands and without the support of cellular infrastructure.

UAV

Lidar USA Provides Helicopter for Its Scanners

Partnering with Innoflight Technology, Lidar USA now offers the Galaxy 950 platform to carry its sensors while providing flight times over 30 minutes. Innoflight designed the Galaxy 950 to simplify the flying aspect of remote sensing with UAVs. The helicopter includes a parachute, automatic takeoff and landing, and extended visual-line-of-sight capabilities to maximize productive time.

For corridor/electric utility line projects, the Galaxy 950 pairs well with the CL-90 by Teledyne Optech. As the first integration partner of the CL-90 compact lidar system, Lidar USA is offering maximum productivity at UAV flight ceilings while achieving improved canopy penetration and exceptional downward point density, the company said.

The partnership is another step for both companies to offer turn-key solutions for quickly and safely acquiring high-quality data.

Photo: Lidar USA

The Galaxy 950 is now available from Lidar USA as an integrated package with any of their scanning systems.

Delivering GPS Capabilities

BY COLONEL JOHN CLAXTON
CHIEF, PNT MISSION INTEGRATION, AIR FORCE SPACE AND MISSILE SYSTEMS CENTER

The Global Positioning System has provided the citizens of the United States and the world the gold standard for positioning, navigation and timing (PNT) for the past 40 years. These days, GPS is seamlessly integrated into our daily lives in ways that we hardly notice. In fact, most of us expect GPS to be available in much the same way that our lights come on when we flip a switch or water comes out when we use the kitchen faucet.

None of this is easy, however, and wouldn't happen if it wasn't for the incredible work and communication by the members of the GPS Program Office and our terrific enterprise partners. During the next 18–24 months, the GPS enterprise will deliver the new and more powerful modernized GPS III capabilities across all segments of the system, which have been in the works and promised for the past 8–10 years. As we transition to the Space and Missile Systems Center's (SMC) 2.0, this is a very exciting time for the GPS program. Below are some updates on our major programs.

Image: USAF

LAUNCH POSTER for GPS III SV02.

Program Updates

GPS III. The space segment of modernized GPS has reached our goals from 2018, and then some. SV01 "Vespucci" launched on Dec. 23, 2018, heralded by celebrations across the GPS community. The GPS III team was honored to share this event with so many giants of the GPS world. We completed space vehicle (SV) 01's On-Orbit Checkout Test in July, meeting and exceeding all performance objectives, and plan to transfer SV01 Satellite Control Authority from SMC to the 14th Air Force by the end of the year. SV01 then begins operational testing and is expected to be certified for full operations in April 2020.

SV02 "Magellan" launched on Aug. 22 aboard a United Launch Alliance Delta IV Medium rocket — the last Delta of its class — to much fanfare and celebration as well. We completed SV02 orbit raising and initial checkout in early September, and Magellan is next in line to transition to operations in 2020.

We received delivery of SV03 and SV04 from Lockheed Martin Space Systems on May 16 and Sept. 10, respectively, with launches targeted for March and July 2020. Challenges remain — this business is hard — but the GPS III team is focused on delivering capability: improving and streamlining the largest big-satellite production line in the Department of Defense and driving our launch campaign to bring modernized capabilities, higher power performance, and the shared international L1C signal to the GPS-using world.

GPS IIIF. The GPS III Follow-On program looks to continue the success of GPS III as it moves forward in production of the first two GPS IIIF satellites. The program is well into a year-long set of detailed design reviews projected to conclude in March 2020. With Lockheed Martin as the prime contractor for both GPS satellite programs, GPS IIIF can take advantage of production-line improvements learned from GPS III to significantly reduce assembly, integration and test timelines.

Additionally, the program is helping to shape SMC's Enterprise Commonality Initiative: an effort focused on aligning common products and processes across multiple programs to improve quality, speed up delivery and lower costs. With plans to procure 22 satellites and a delivery timeline spanning 15 years, the program has implemented a technology-insertion strategy and partnered with the Air

Force Research Laboratory to ensure a timely transition of new capabilities to meet future military requirements. It is great to see the progress GPS IIIF is making in delivering its new baseline capabilities along with the steps it's taking toward future capability insertion. The first GPS IIIF satellite launch is forecast for 2026.

GPS Next Generation Operational Control System (OCX). This past year, we used OCX Block 0, also known as the GPS III Launch and Checkout System, to launch and initialize both GPS III SV01 and SV02 and have been flying them in caretaker status until they are ready to be incorporated into the operational constellation. On OCX Block 1, all coding is complete, and the program focus is transitioning from development to system integration, test, and then transitioning the system to operations. Program investments over the past couple of years to change the program culture and modernize the factory infrastructure (often referred to DevOps) is paying off and yielding real-time metrics used to make data-driven decisions and produce higher quality code at a significantly faster rate. As a result, OCX is no longer troubled, but is now a typical large-complex software-intensive program that will experience challenges and risks. Fortunately, the right tools are in place to deliver this critical capability.

GPS Legacy Ground Sustainment. We continue to sustain our existing GPS infrastructure associated with the current Operational Control System (OCS). These sustainment efforts ensure GPS will continue to deliver the gold standard in PNT while providing the crucial on-ramp to incorporate the next generation of modernized GPS capabilities. We operationally accepted the largest OCS upgrade in GPS history. This upgrade, known as Version 7.5, virtualized the network, implemented two-factor authentication, secured connections to worldwide ground antennas, and improved encryption for mission data.

Challenged with a need to rapidly mitigate mission risk and provide enhanced cyber protection, the Red Dragon Cybersecurity Suite (RDCSS) emerged as the GPS OCS monitoring platform, providing data aggregation, analytics and multi-level Indicators of Compromise (IOC). It has evolved into an efficient and effective means to detect, investigate, and report security events and incidents.

Additionally, in August 2019 we established an RDCSS connection into the Space Enterprise Defensive Cyber Operations (DCO) solution, known as the Cyber Defense Correlation Cell for Space. This created a layered defense and a tiered DCO environment for protecting and sustaining the GPS mission.

GPS User Equipment. Over the past year our soldiers, sailors, marines and airmen continued testing and integrating mature, next-generation GPS receiver cards that provide more accurate and reliable positioning, navigation and timing. The first Military GPS User Equipment (MGUE) receiver card was qualified this year, and the core technologies are being leveraged to develop many other types of GPS receiver cards for a wide range of DoD weapon systems. This exciting work is the culmination of nearly two decades of modernization efforts throughout the GPS enterprise.

In the near term, we are utilizing M-code-capable lead platforms — the USAF B-2 Bomber, USMC Joint Light Tactical Vehicle, USN Arleigh-Burke Class Guided Missile Destroyer and Army Stryker combat vehicle — to prove those capabilities. The second increment of MGUE now underway will focus on requirements for precision-guided munitions, a joint common modular handheld unit, as well as circuit cards and components for low size, weight and power needs. With MGUE, the DoD and services are poised to have enduring PNT solutions the warfighter can leverage for years to come.

GPS Integration Roadmaps

Integration of modernized GPS III capabilities into our major programs is a key focus of the GPS Program Office as we deliver capabilities to our warfighter and civilians users. We have continued to refine our plans and further integrate our programs and teams to ensure a seamless transition and continued high level of service.

Enterprise Road to Launch (ERTL). The Road to Launch team achieved an historic victory of firsts in December 2018. We successfully launched GPS III SV01, the first of its class. SMC partnered with SpaceX to launch SV01 aboard a Falcon 9 rocket — their first National Security Space Launch. SV01 reached orbit under the command and control of our first GPS OCX delivery, the GPS III Launch and Checkout System. This colossal accomplishment of firsts was only possible because of the exceptionally close integration, tenacity and highly collaborative effort among all players in the community — spacecraft, payloads, launch, control, signal monitoring, acquisition, operations, test and many others. For SV01, the ERTL has now passed the torch to the Enterprise Road to Mission team — but the Road to Launch team is as busy as ever. The mission planners, launch and orbital operations crew ensured SV02 reached medium Earth orbit with needle-threading precision in August; the team is implementing improvements based on experience as we prepare for up to three more GPS III launches in 2020; and we are already ramping up efforts to design the launch campaign for GPS IIIF.

GPS Enterprise Road to Mission (ERM). With two GPS III satellites now on orbit, it is now time to execute the Enterprise "Integration Playbook" we have developed

See GPS, page 49. >>

Galileo Moves Ahead

BY JAVIER BENEDICTO
HEAD, GALILEO PROGRAMME DEPARTMENT,
EUROPEAN SPACE AGENCY

Since the Galileo initial services declaration in December 2016, the Galileo Program has been providing global PNT and search-and-rescue services for users worldwide. The European GNSS Agency (GSA) just issued its *GNSS 2019 Market Report* in October, providing a complete overview of the current status and trends of the GNSS worldwide market with focus on European GNSS (Galileo and EGNOS) applications and services.

In parallel with service provision, the Galileo Program is undertaking extensive infrastructure development and deployment activities to reach Full Operational Capability (FOC), incorporating new service capabilities, but above all aiming at increasing the robustness and resilience of the system infrastructure, operations and service provision.

Galileo's signal-in-space quality has steadily improved over the past few years, reaching in 2019 a best signal-in-space error (SISE) of about 0.25 meters (95%, global average; **FIGURE 1**). This has been achieved through a combination of several factors, including the increased number of operational satellites, enhanced versions of the Ground Mission Segment, and higher uplink rate of the navigation message (lower age of data). This performance is well within Galileo's initial service accuracy commitments, as defined in the public Open Service - Service Definition Document (OS SDD).

FIGURES 2 and **3** (see page 40) show Galileo's timing performance as broadcast UTC offset and GGTO accuracy. The evaluation was performed with calibrated GPS/Galileo timing receivers operated in UTC(k) laboratory (PTB, INRIM). Again, the initial timing service commitments have been fully met.

Probably the most significant discriminator of Galileo compared to other GNSS is its capability to broadcast multi-frequency (E1, E6, E5) signal components on all operational satellites. The position performance of a dual-frequency user receiver on-ground is shown in **FIGURE 4** (see page 40). This measurement from June 2019 demonstrates a Galileo position accuracy well below 2 m (95%).

Photo: ESA

GALILEO TELEMETRY and telecommand ground station.

With the aim of further improving the Open Service (OS) performance, three newly introduced I/NAV message improvements on Galileo E1-B are under implementation, namely FEC2 Reed-Solomon Clock and Ephemeris (CED), Reduced CED, and Secondary Synchronization Pattern (SSP). Galileo Open Service (OS) users will benefit from improved robustness in terms of navigation data retrieval in challenging environments, in addition to facilitating a reduced time to first fix. Those I/NAV improvements on Galileo E1-B are backwards compatible with previously released OS SIS ICDs.

In addition, Galileo infrastructure is currently being upgraded to provide means for OS authentication. The protocol proposed uses the E1B External Data Broadcast Service (EDBS) to provide authentication data to the user. The OS Navigation Message Authentication (NMA) is based on an adaptation of the Timed Efficient Stream Loss-tolerant Authentication (TESLA) protocol.

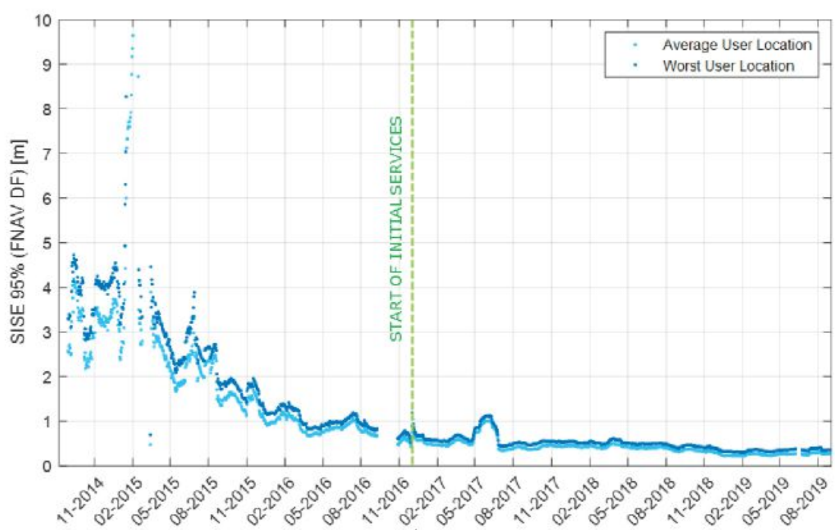
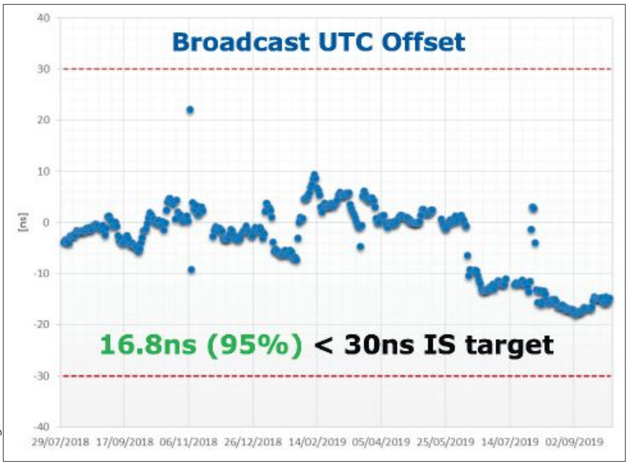


Image: ESA

FIGURE 1. Long-term historical SISE plot over a 30-day sliding window, constellation averaged.

BROADSIM
WAVEFRONT
orolia
DEFENSE & SECURITY
AVAILABLE
NOW
NEXT-GEN NAVWAR SIMULATION
CONFRONT CHALLENGE
WITH CONFIDENCE
Designed for multi-element
antenna testing like CRPA's
Calibrate GNSS frequencies
in a matter of seconds
Simulate spoofers, jammers,
repeaters, and alternate PNT
sensors with just a few clicks
Scalable from 4-16 elements
at 1,000 signals per element
and 1,000 Hz iteration rate
Phase coherence of 1°σ
Dynamic range of >130 dB J/S
POWERED BY
skydel
GNSS SIMULATION
→ SALES@OROLIADS.COM | OROLIADS.COM/BROADSIM-WAVEFRONT



Images: ESA

Figure 2. Galileo Broadcast UTC offset accuracy performance.

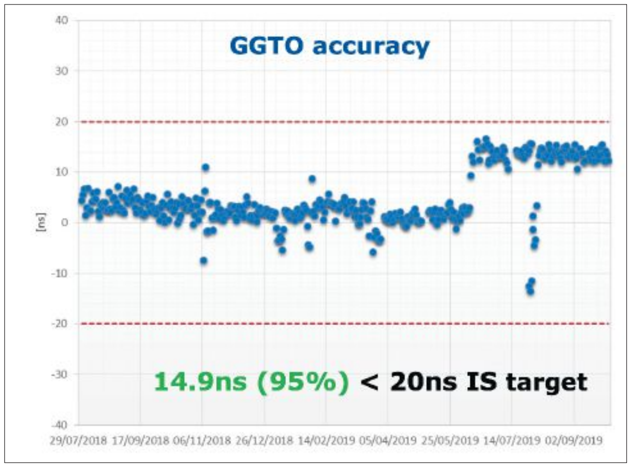


Figure 3. Galileo GGTO offset accuracy performance.

Beyond the OS, the Galileo system has been designed to allow for the dissemination of value-added data, such as high accuracy and authentication, in the E6B signal component. The component has been designed to broadcast the Galileo High Accuracy Service based on the provision of accurate satellite data (clocks, orbits and biases) and atmospheric data (mainly ionospheric corrections) to enable multi-frequency multi-constellation PPP with correction data transmitted through an open format in the Galileo E6B signal.

The introduction in early 2020 of the automatic acknowledgment of the SAR/Galileo Return Link Message (RLM) as part of the Cospas-Sarsat system will enable space assets to

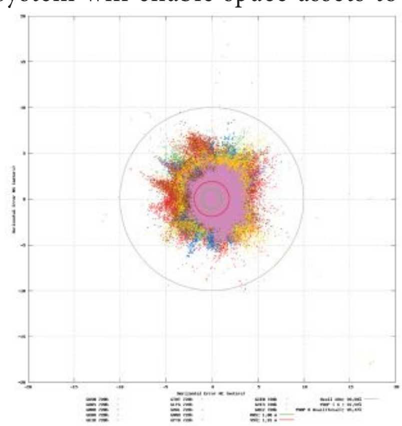


Image: ESA

Figure 4. Galileo position accuracy performance, dual-frequency, June 2019.

be used for search and rescue — persons in distress will get swift acknowledgement that their alert has been detected and located. The Return Link is the means to interact with a SAR beacon, improving the effectiveness of SAR operations. Extensive testing has demonstrated that the median latency for the reception of a return link message on the ground is 14.2 seconds, while 99% of messages are received within 57 seconds, after the request for the RLM transmission is delivered to Galileo (from Cospas-Sarsat to the RLSP). At the same time, the measured rate of reception was 100%, considering line-of-sight availability, thanks to the very robust Galileo navigation data link. This performance has been demonstrated to be uniform across the globe, as shown in **FIGURE 5** (see page 46).

Following the re-profiling of the Galileo Safety-of-Life (SoL) service, Galileo is meant to be exploited through dual-frequency multi-constellation (DFMC) SBAS and will support the provision of integrity through the concept of Horizontal Advanced Receiver Autonomous Integrity Monitoring (H-ARAIM). To allow the exploitation of Galileo for these SoL applications, a thorough analysis of the actual signal-in-space (SiS) performance and of potential feared events critical for SoL users is key. In this context, the Galileo Integrity Failure Mode and Effect Analysis (IFMEA) process is implemented through measurements and review of the system design, including feared-events characterization.

Ground Segment Brings Robustness

Galileo's Ground Segment is being upgraded to fully redundant control centers. These include processing and storage, monitoring and control facilities, and security monitoring centers. A worldwide network of Galileo Sensor Stations (GSS) allows monitoring and measuring of satellite signals; uplink stations allow dissemination of the navigation message to users through Galileo satellites; and telemetry, tracking and control (TTC) stations allow monitoring and control of the satellites.

Ground segment upgrades under production by Thales Alenia Space France (in charge of the ground mission segment and security monitoring) and GMV Spain (in charge of the ground control segment) are addressing increased service robustness, through the introduction of a more flexible infrastructure with a significant technology refresh, improved security, service continuity, enhanced service performances, and enhanced operability features.

One important objective of the

ongoing upgrades is to implement a modern infrastructure, based on leading virtualization technologies. This modernized infrastructure will make it possible to easily accommodate hardware and software changes without requiring significant redesign or requalification, and will minimize the impact to Galileo service operations — under responsibility of Spaceopal GmbH — during future deployment activities.

Batch 3, Ariane 6 Under Production

The production of Batch 3 of 12 additional Galileo FOC satellites is proceeding, aiming at readiness for launch by the end of 2020 onward. The satellite design includes a selected number of improvements compared to the 22 FOC satellites launched previously and built by the same satellite manufacturer OHB Systems.

Artist's impression: ESA

ARIANE 6 on the launchpad.

The different stages of assembly, integration and initial test phase in the OHB production plant in Bremen have already started, before shipment to ESA-ESTEC in the Netherlands for the environmental test campaign consisting of thermal vacuum, mechanical tests, interface verification with the launcher and system end-to-end performance tests with the elements of the Galileo ground segment.

Following the phasing out of the Ariane 5 SE launcher, the third batch of Galileo satellites will be progressively launched with the new Ariane 62 launcher vehicle, the two solid-booster variant of Ariane 6 now in the final stages of development.

Evolution to Meet User Needs

The Galileo Second Generation roadmap has achieved maturity in 2019 and is now entering the preliminary design and implementation phase. Based on the EU's H2020 Galileo

SEE GALILEO, PAGE 46. >>

BeiDou in the New Era of Globalization

Photo: BeiDou

BY YANG CHANGFENG
CHIEF ARCHITECT,
BEIDOU NAVIGATION SATELLITE SYSTEM

As one of the core Global Navigation Satellite Systems (GNSS) providers, the BeiDou Navigation Satellite System ("BDS") has been developed steadily following a three-step strategy. BDS has been providing global services since the end of 2018. By around 2020, the BDS-3 system will be entirely completed to provide global users with free, open and high-quality navigation, positioning, timing, short message communication and other services. A more ubiquitous, integrated and intelligent positioning, navigation, timing system will be built before 2035.

In 2019, BDS has progressed with regard to aspects of system construction, integrated applications and international development

System Construction

Accelerating Satellite Deployment. From January to November 2019, three BDS-3 satellites in inclined geosynchronous satellite orbit (IGSO) and four satellites in medium Earth orbit (MEO) were launched, and one IGSO satellite has completed in-orbit tests, to further improve the global system constellation.

The last two MEO satellites are planned to be launched by the end of 2019, marking the completion of the BDS core global constellation deployment. By June 2020, another two GEO satellites will be launched, and the full deployment of the BDS-3 system will be completed.

Ground System Construction. In 2019, 12 new ground operation and control stations (including one uplink station and 11 class-II monitoring stations) have been built, to complete the satellite-ground joint debug and integration tests, and the overall operation of the system is stable.

By the end of October 2019, 34 BDS satellites are operating in orbit to provide services to global users, including 15 BDS-2 satellites and 19 BDS-3 satellites.

Improving Service Performance

Key Service Areas. In May 2019, the last BDS-2 backup satellite was launched to further improve the performance in the key service areas of the BDS-2 system. As the BDS-3 satellites go into operation, the accuracy and availability of the BDS B1I and B3I signals, in the BDS-2service area, has been improved by about 30% and 5% respectively, compared with that of solely relying on the BDS-2 system.

Global Service Areas. The BDS B1I and B3I service areas have been expanded from the Asia Pacific region to the world, and the accuracy and availability have been further improved. With the condition of PDOP ≤6, the availability is better than 99% in most regions all over the world (in parts of the United States, better than 97%). In the global area, the mean value of the actual measured positioning accuracy is about 3.6m horizontally and 6.6m vertically, velocity measurement accuracy is about 0.05m/s, and timing accuracy is about 9.8 nanoseconds (95% confidence). So far, the BDS-3 new signals, B1C and B2a, have possessed service capacity worldwide. The system availability is better than 87%, in the condition of PDOP ≤ 6. The mean value of the actual measured positioning accuracy is about 2.4m horizontally and 4.3m vertically, velocity measurement accuracy is about 0.06m/s and timing accuracy is about 19.9 nanoseconds (95% confidence).

Building of the Featured Capacity. The BDS/GNSS ground based augmentation system has been providing basic services. It consists of 155 framework reference stations and nearly 2,200 regional stations in China. The system has carried out high-precision applications in many fields, such as surveying and mapping, land resources, earthquake, transportation and meteorology. Its basic services include real-time positioning at the meter, decimeter and centimeter level, as well as precise post-processing positioning at the millimeter level. The BeiDou Satellite-Based Augmentation System (BDSBAS) is being developed in accordance with International Civil Aviation Organization (ICAO) standards to provide navigation services with superior accuracy and integrity. In 2019, the first GEO satellite with the BDSBAS payload has been tested in orbit and the satellite is in good condition.

Integrated Applications

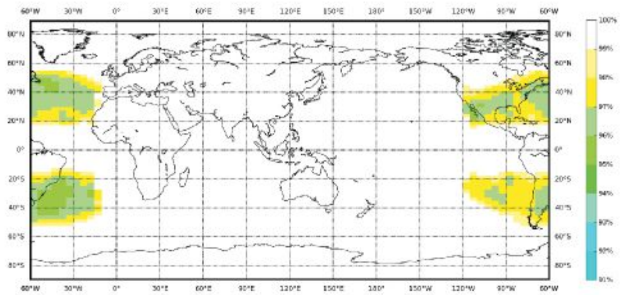
As the system construction accelerates, BDS is also making great efforts to strengthen the development of the fundamental products and applications in various fields. The integrated applications adopt the "BDS+" model to stimulate the growth of satellite navigation industry.

Fundamental Products. At present, the fundamental BDS products have been used in such areas as mass market applications, of which the performance has reached or is close-to the world-class level. The development of full-frequency integrated high-precision chips is near its completion, and the performance of the BDS chips will improve further. By the end of 2019, BDS navigation chips, modules and antennas have been exported to more than 100 countries and regions. In 2018, the domestic output value was more than RMB 300 billion (US$43 billion), in which the BDS contribution exceeds 80%.

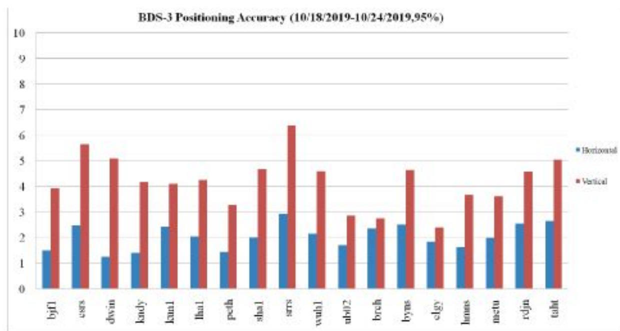
Industrial Applications. BDS has been widely used in various fields — communication and transportation, public security, agriculture, forestry, animal husbandry and fishery, hydrological monitoring, meteorological forecast, time synchronization, power dispatching, disaster prevention and mitigation — generating significant economic and social benefits. In the field of transportation, by September 2019, more than 6.47 million road operating vehicles and 42,300 postal and express delivery vehicles in China are using BDS, and the world's largest dynamic supervision system of operating vehicles has been formed, which effectively improved management efficiency and road transportation safety. In agriculture, a BDS-based automatic driving system has been equipped on more than 20,000 sets of

SEE BEIDOU, PAGE 48. >>

Images: Beidou



BDS AVAILABILITY (PDOP≤6).



MEASURED BDS B1C Positioning Accuracy.

GLONASS Focuses on Users

BY YURY URLICHICH, FIRST DEPUTY DIRECTOR GENERAL OF ROSCOMOS STATE SPACE CORPORATION,
SERGEY KARUTIN, DESIGNER GENERAL OF GLONASS, AND NIKOLAY TESTOEDOV, DIRECTOR GENERAL, INFORMATION SATELLITE SYSTEMS

Roscosmos keeps concentrating on user needs as it did in previous years. Growing digitalization is driving a high demand for high-accuracy navigation services. Space information technologies support user needs by modern digital services, including increasing accuracy of position and velocity determination. Because of this, it is of vital importance for us to ensure that GLONASS provides continuous services and stable performance.

Performance Standard & ICD

This year, we finished drafting the GLONASS Open Service Performance Standard (GLONASS OS PS; the Russian language version is available at **www.glonass-iac.ru/GLONASS/stehos/stehos.pdf**). In 2020, the new version of the GLONASS Interface Control Document (ICD) also will be publicly available.

GLONASS OS PS serves as a high-level mainframe document specifying the values of the achieved GLONASS performance characteristics plus the significant guaranteed margin. These, coupled with the signal reception environment and a priori estimation of user equipment performance characteristics, can further be translated into the performance that an end user can expect to achieve in his specific PVT solution.

This GLONASS OS PS is a basis for certification of GLONASS services and development of lower level standards for user receiver and GLONASS-based service, as well as for development of international standards like those of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and others.

Use of the unified set of performance parameters and calculation methods for all GNSS — GLONASS, GPS, Galileo and BDS — is a conventional practice. The similar standards for GPS, Galileo and BDS have been published and are regularly updated.

In fact, this GLONASS OS PS is the second one after the ICD baseline interface between GLONASS and user receiver manufacturers and the GLONASS-based services developers. The OS PS establishes the minimum performance that can be achieved by users with a high level of trust based on the system's long-term statistical history.

Signal-in-Space. This OS PS specifies standards for the GLONASS OS Signal-in-Space (SIS) performance neglecting receiver biases, signal propagation and reception biases (in terms of performance metrics used to specify system performance, that is, taking into account the GLONASS space segment and the GLONASS ground segment contributions to the performance). It can serve as a basis for certification of the GLONASS-based services and receivers incorporating GLONASS, including those used in aviation and other user domains.

The OS PS provides an overview of the GLONASS system and an overview of the GLONASS Open Service SIS. It specifies the standards for the performance characteristics of the channel of standard accuracy used to provide the Open Service, and lists the legal reference documents.

L3 CDMA. One of the most significant tasks is the harmonization of GLONASS user interfaces with respect

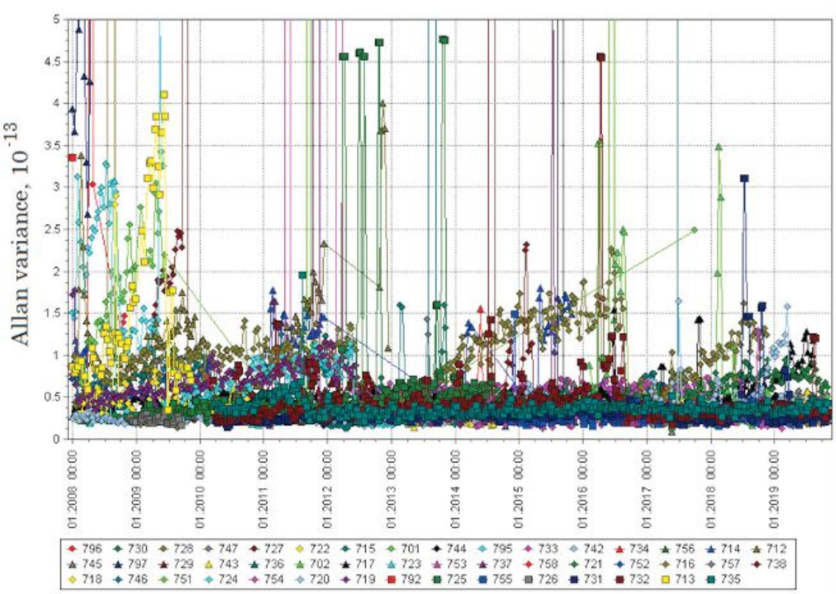


Image: ROSCOSMOS

FIGURE 1. **Mature Glonass-M satellites show improved cesium frequency standards performance in terms of daily stability.**

to new L3 CDMA signals. The requirements related to the interface between the space segment of GLONASS and the navigation user segment for radio frequency links is established by the GLONASS ICDs.

The new version of ICD for CDMA L1, L2 and L3 signals to be broadcast by new-generation Glonass-K2 satellites was issued in 2016. However, the Glonass-M satellites (## 755-758) and the Glonass-K satellites currently in orbit transmit the L3 signal as per the L3 Open Access CDMA Radionavigation Signal Interface Control Document (Edition 1) of 2011.

In order to mitigate the above-mentioned discrepancies, five reference documents (Interface Control Documents for open-access signals) have been updated and prepared for publication. In addition, flight tests to verify new ionospheric and tropospheric delay models have been scheduled.

Incorporating More Data

The new ICDs for open access and authorized signals incorporate changes related to the introduction of additional data into the spare bits of the navigation message. This additional data is to be used by user receivers for better PVT solution purposes.

The updated versions of ICDs will incorporate:

- The mathematical ionospheric delay model and inclusion of the model parameter into the navigation message.
- The mathematical tropospheric delay model, which does not require that any specific parameters be included into the navigation message. It only employs data on the latitude of a user receiver location and the season (i.e., winter, spring, summer, and autumn).
- The attribute (or flag) to inform a user that a satellite is in the turn mode and its antenna phase center behavior is different from that when a satellite is in the sun orientation mode.
- Information about the types of signals broadcast on the L1, L2, and L3 frequencies; 5-bit field, in which the first three bits denote L1, L2, and L3 CDMA signals, respectively, while the 4th and the 5th bits denote L1 and L2 FDMA signals, respectively.
- A 5-bit field to be used to broadcast age of data (AOD) for time offsets in addition to the similar field used to broadcast AOD for ephemerides.

Backward Compatibility. The updated CDMA and FDMA ICDs will support the backward compatibility for the

See GLONASS page 47. >>

GALILEO

« Continued from page 41.

Second Generation activities managed by ESA, and the GSA prospective market analysis, the European Commission, in close consultation with EU member states, has agreed on an ambitious set of long-term PNT goals for the future European GNSS infrastructures.

Technology pre-developments, critical engineering activities and synergic design activities between space and ground infrastructure are being conducted. This will translate into the progressive deployment of a complete set of space/ground infrastructure that is tailored to satisfy the diversified user needs in four main dimensions:

- Satellite and ground segment infrastructure with capabilities that can dynamically adapt to current and future user needs. Key drivers are flexibility and robustness, ensuring fast time to market to meet user needs.
- Full synergy between GNSS and SBAS systems infrastructure, to complement and enhance the service portfolio. This will allow segmentation and complementarity of safety-critical services and extension to all new PNT services available today, including high-accuracy positioning integrity.
- Enhanced integration with terrestrial systems — 5G/6G, signals of opportunity (SOOP), terrestrial beacon systems (TBS). ESA and GSA have been actively leading the 5G positioning standardization worldwide in collaboration with public and private institutions inside 3GPP and will soon move toward the start of standardization of

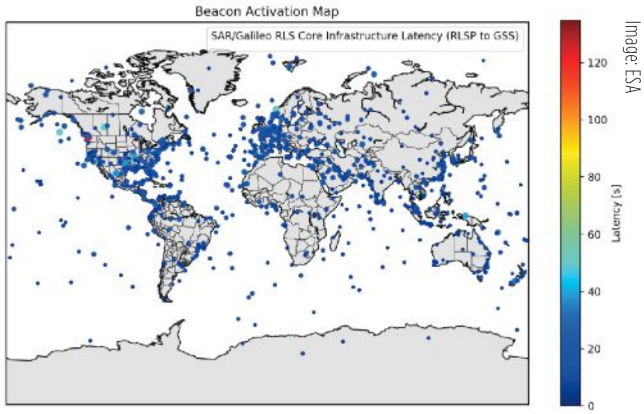


Figure 5. Beacon activation map and RLM delivery latency through the Galileo system.

6G terrestrial positioning and GNSS interconnection technologies.

- Full complementarity with external sensors (such as INS, barometer and lidar) and application environments (low-power devices and internet of things) so that the Galileo Second Generation Infrastructure enhances and complements the capabilities provided by these external means.

A key pillar for this long-term strategy is the Galileo transition satellites. The competitive procurement procedure for the first batch of transition satellites is coming in 2020. The flexibility and robustness of these satellites will allow the European PNT infrastructure to satisfy all the different user needs in the next decade. This procurement — together with others at system, ground segment and technology level — will enable the start of the in-orbit validation of second-generation capabilities from 2025 onward.

Additional ground and test infrastructure are in early engineering analysis, design and technology development, in order to proceed with additional procurements for experimental and operational usage, starting early in the 2020s. 🌐

GLONASS

<< Continued from page 45.

uninterrupted operation of the existing envelope of user equipment and the introduction of the ionospheric and tropospheric model parameters into the message spare capacity.

Constellation Refresh

The GLONASS constellation has been replenished steadily. Since 2013, we have been launching one to two satellites a year, and this year is not an exception. The launch on May 27 and the December launch will help sustain the nominal constellation. The Glonass-M satellites demonstrate good dynamics for the average operational life. Two satellites are well beyond their 10-year design life — their operational lifetime has exceeded 12 years. As some of the Glonass-M satellites grow older, their cesium frequency standards performance in terms of daily stability improves (see **FIGURE 1**, page 44).

Glonass-K. In 2020, the launch campaign for the Glonass-M satellites will come to its end. The Glonass-K satellites will come on stage with the first launch of Glonass-K-15 scheduled for the beginning of the next year. We are fully confident that this satellite will not disappoint our users. 🌐

BEIDOU

« CONTINUED FROM PAGE 43.

agricultural machinery and equipment, saving 50% of the labor cost. The BDS-based agricultural machinery operation supervision platform and the IoT platform has been serving 10 million units of agricultural machinery equipment, greatly improving management and operational efficiency. In disaster prevention and mitigation, a tri-level platform covering the national ministry, the provinces, and cities and counties has been built to offer six-tier application services, with more than 45,000 terminals using BDS. The BDS/GNSS high-precision technologies have been applied in the field of geological disaster monitoring, while the landslides in Gansu province have been successfully forecast repeatedly, with time accuracy at the second level and deformation accuracy at the millimeter level.

Mass Market Applications. The BDS-based navigation and positioning services have been adopted by various enterprises in the fields of e-commerce, smart mobile terminal manufacture, location-based services (LBS), the sharing economy and the mass market, thereby changing people's production and life style profoundly. Mainstream manufacturers in China and around the world have introduced BDS-compatible chips that integrate communication and navigation functions. According to Chinese market statistics, in the third quarter of 2019, 151 types of mobile phones applying for license have positioning functions, among which 110 models support BDS. Using BDS/GNSS ground based augmentation stations, the spatial-temporal services including centimeter-level positioning, millimeter-level perception and nanometer-level timing services can be provided, while the accelerated positioning services cover 220 countries and regions with more than 390 million global users.

International Development

Bilateral Cooperation. BDS continues to carry out bilateral cooperation with other navigation satellite systems, to promote compatibility and joint applications. China and the United States have set up joint working groups in areas such as compatibility and interoperability, augmentation systems and civil services to continuously develop cooperation and exchanges. China and the EU set up a technical working

ADVERTISER INDEX: COMPANIES FEATURED IN THIS ISSUE

Editor's Note: This ad/edit index is for reader convenience only. Publisher accepts no responsibility for errors or omissions.

group on the compatibility and interoperability between the BDS and Galileo systems to carry out coordination, exchanges and cooperation, under the framework of the China-EU space cooperation dialogue and the International Telecommunications Union (ITU). The agreement between the Government of the People's Republic of China and the Government of the Russian Federation on Cooperation in the Field of the Use of BeiDou and GLONASS for Peaceful Purposes has come into effect. In August 2019, China and the Russian Federation held their sixth bilateral meeting in Kazan, Russia, signed the site survey certificate of GNSS monitoring stations, and achieved many cooperation results. In addition, the bilateral cooperation with Iraq, Tunisia and Saudi Arabia has also been steadily promoted.

Multilateral Cooperation. During the 62nd session of the Committee on the Peaceful Uses of Outer Space (COPUOS) in June 2019, an exhibition on ancient Chinese navigation technologies was held at the Vienna International Center with the theme "From Compass to BeiDou," which vividly demonstrated China's brilliant achievements in timing, mapping, cartography and navigation science and technology. In April and October, 2019, the second China-Arab States BDS Cooperation Forum and China-Central Asia BDS cooperation forum were held in Tunis and Nanning, China, respectively, to promote the BDS to serve the Arab region and Central Asian countries.

The BDS Overseas Applications Were Steadily Promoted. With BDS high-precision products being exported, BDS has been widely used in different regions and fields, such as land registration, precision agriculture, warehouse logistics in ASEAN countries, construction in Western Asia, airport timing and piling at seas in South Asia, electric power inspection in Eastern Europe, and land survey in African countries. As BDS-3 system continues to improve construction, it will provide quality services for more people in a wider area.

Ratification of BDS by International Standards. BDS has made a clear schedule to be ratified by the ICAO standards in 2020. It has formulated 26 standards in the field of international mobile communication based on the BDS B1I signal, and other standards based on the B1C and B2a signals are being developed. A receiver positioning result output protocol (NMEA0183) and a receiver data exchange format (RINEX 3.04) supporting BDS are to be released. Technical parameters and index information of BDS search and rescue (SAR) payloads are included in relevant COSPAS-SARSAT documents, and the development and in-orbit test of the first batch of SAR payload has been completed. The first BDS standard in the International Electrotechnical Commission (IEC) has been developed and approved and is expected to be released in June 2020.

Future Plans

After BDS achieves global service capabilities by 2020, it will further improve global navigation, positioning, timing and regional short-message communication services, and finalize global short-message communication, international search and rescue, satellite-based augmentation, precise point positioning, and other service capabilities. China's BDS will contribute Chinese solutions to the world, and give full play of its role, with a renewed attitude, stronger capabilities and better services, to serve the world and benefit humankind.

GPS

« *Continued from page 37.*

and coordinated over the past year. The Contingency Operations (COps) modification upgrade has now been integrated into OCS on the 2 SOPS operations floor and is undergoing Developmental Testing with the GPS III SV on orbit. The program anticipates operational testing in January 2020 and Operational Acceptance in April 2020. All of our community stakeholders are ready, and with the COps modification to OCS in place, it is time to get the GPS III satellites into mission and start providing its new capabilities to our users. Over the next few months, the GPS III capabilities are expected to be operationally certified and ready for use.

GPS Enterprise Road to M-Code Mission (ERM-M-Code). With COps now in place, the next major delivery will be M-Code Early Use modification to OCS, installation of new M-code signal monitoring equipment at sites around the globe, modification of mission planning software, MGUE Increment 1 development, service lead platform integration efforts, and operationalization of space receivers. It is our continued objective to improve the ability of the Combined Space Operations Center, to respond to urgent PNT needs of the combatant commanders as they engage more sophisticated adversaries. We remain closely aligned with our peers at USSTRATCOM, AFSPC and our worldwide users across the Joint Service and allied team.

Conclusion

It has never been a more exciting time to be part of the GPS program and enterprise. Our outstanding government and contractor teams have worked so incredibly hard on integrating and communicating our programs to ensure the successful and seamless delivery of GPS III capabilities to both our warfighter and civilian users. It is a great world we live in today, and GPS makes it even better.

SEEN & HEARD

GET THOSE SUB SANDWICHES TO THE SUB!

On Oct. 10 a small quad-rotor drone resupplied a U.S. Navy submarine, the *USS Hawaii*, a mile off of Oahu, Hawaii, in partnership with the University of Hawaii Applied Research Lab. The 5-pound payload consisted of circuit cards, medical supplies and food. Using UAVs rather than manned helicopters to resupply subs saves costs, keeps pilots safe, and frees up helicopters for larger missions.

SIGN OF THE TIMES

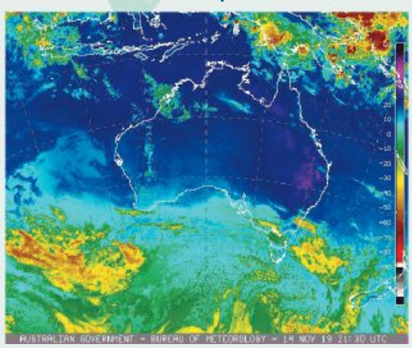
A shopping mall in Fair Oaks, California, is taking the ubiquitous location pin to heart. KRCA-TV reports that the new sign at the entrance to the Corcos Square strip mall is drawing criticism from some residents who see it as less eye-catching than eyesore. Others think it highlights the neighborhood, and makes it harder for visitors to overlook.

UBER UNVEILS FOOD-DELIVERY DRONE

Uber Elevate, Uber's aviation division, has unveiled a new food-delivery drone. The six-rotor UAV is vertical- and horizontal flight-capable, has a range of 18 miles and an 18-minute flight time, and can carry enough food for two adults. The drones will land in designated safe-landing zones, where human couriers will pick up the food and bring it to customers' doors. The company might also land the drones on parked Uber cars (tagged with QR codes), which will carry the meals to their final destinations. The program is expected to roll out next summer in San Diego.

REFUELING ON THE FLY

The U.S. Navy and Boeing on Sept. 19 completed the first test flight of the MQ-25 unmanned aerial refueler. The MQ-25 completed the autonomous two-hour flight under the direction of Boeing test pilots at a ground control station at MidAmerica St. Louis Airport in Illinois. The aircraft completed taxi and takeoff, and then flew a predetermined route to validate basic flight functions. Once delivered to the carrier fleet, the MQ-25 will give the Navy carrier-based aerial refueling capability, extending the range of the carrier air wing.



SIGNALS FROM ABOVE FOR DOWN UNDER

Australia's Bureau of Meteorology has started using GNSS signals in its forecast modeling. Because GNSS signals become slightly delayed by water in the troposphere, by precisely measuring this "zenith total delay," researchers can calculate the air's moisture content and likely rainfall patterns. They're also studying how the distortion of GNSS signals can be used to determine temperature at different altitudes.

PHOTO CREDITS: Submarine/U.S; Navy; Uber food-delivery vision/Uber Elevate; location pin sign/KRCA-TV screenshot; weather map/Bureau of Metrology; MQ-25 test/Boeing

GPS WORLD (ISSN 1048-5104) is published monthly by North Coast Media LLC, IMG Center, 1360 East 9th Street, Tenth Floor, Cleveland, OH 44114. **SUBSCRIPTION RATES:** For U.S., Canada and Mexico, 1 year $89.95 print and digital; two years $148.95 print and digital. All other countries, 1 year print and digital $159.95 2 years $265.95. For air-expedited service, include an additional $75 per order annually. Single copies (prepaid only) $10 plus postage and handling. For current single copy or back issues, call 847-763-4942. **Periodicals postage paid** at Cleveland OH 44101-9603 and additional mailing offices. **POSTMASTER: Please send address change to GPS World, PO Box 2090, Skokie, IL 60076.** Printed in the U.S.A.


NovAtel
NovAtel