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Next-gen GPS III satellites feature longer lifespans, 3x the accuracy, and 8x the anti-jamming capabilities

Simulator Buyers Guide

L1C Signal's First Unveiling

Inertial-RTK Drives Autonomously

A NORTH COAST MEDIA PUBLICATION

MARCH 2019 | Vol 30 | No 3

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MARCH 2019

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MARCH 2019

OPINIONS AND DEPARTMENTS

Photo: NASA

MARKET WATCH

Image: Inertial Sense

ONLINENOW

NEWSLETTER EXCERPT

Making It Safe for Drones to Fly over People

BY Tony Murfin
CONTRIBUTING EDITOR, PROFESSIONAL OEM + UAV

Changes to the FAA operational drone restrictions were recently proposed to allow some flights over people. This appears to be a major step forward. Mail-order delivery flights, newsgathering, real-estate sales movies and building inspection all begin to make more sense, maybe even become viable. Some night operations could also be possible.

Risk assessment methodology appears to be logical; a number of UAV categories are proposed, and there is a way to assess if operators are in compliance.

A ground impact study sought to determine the possible risk of injury to people from drones falling out of the sky. Assessments were made using existing automotive standards and a military standard for debris impact, plus there was testing using automotive crash dummies. The bottom line is that possible injuries to people are more likely to be minor than major.

However, a retired military major suggests that although the conclusion of the assessment was that 2 kilos (4.4 pounds) was an OK weight for an sUAV to avoid serious injury to anyone, the FAA appears to have proposed limitations for sUAS which are only 1/10th of this weight…

Read the full column at **www.gpsworld.com/opinions**.

LOOKING FOR THE RECEIVER OR ANTENNA SURVEY?

They won't appear in print this year, but 2018 versions of both are online.

gpsworld.com/resources/gps-world-receiver-survey
gpsworld.com/resources/gps-world-antenna-survey

Galileo's Crucible

BY ALAN CAMERON
EDITOR-IN-CHIEF

Gazing through soaring plexiglass walls at the space simulation room of the European Space Agency's Test Center in the Netherlands affords a glimpse into scientific history.

I felt a frisson, a highly regimented frisson if you will, of vicarious thrill for the rigors, rhythms and methods of research and testing as I toured the center after giving a keynote at the agency's Navigation Days. Here, the final birthing touches were administered to transmitters beaming forth the Second Golden Age of satellite-based navigation.

One can debate which constellation combination will prove most fruitful to users: GPS plus GLONASS, GPS plus BeiDou, GPS plus Galileo (note the common term). I believe it will be the last, because of the close synergy and symbiosis of the two commercial arenas, North America and Europe.

All Galileo Full Operational Capability (FOC) satellites had their mettle and metals probed, radiated, bombarded, shaken and shocked here before they journeyed to space. The test center's role is to verify, intensively and for months per satellite, that it can perform well for the whole of its planned lifetime.

A mass property test checks that the center of gravity and mass are aligned within design specifications, so that the satellite's orientation can be accurately and economically controlled with thruster firings in orbit, prolonging work life by conserving propellant.

A five-week thermal-vacuum test runs inside a 4.5-meter diameter stainless steel vacuum chamber, the Phenix. An inner thermal tent heats to simulate solar radiation and cools with liquid nitrogen to create the chill of sunless space.

In the Maxwell test chamber, spiky radio-absorbent anechoic walls test electromagnetic compatibility to ensure that all systems operate together without interference. Noise horns generate more than 140 decibels to simulate a violent launch. A quad shaker table vibrates the satellite up, sideways and down, as accelerometers search for hazardous internal vibration, gathering data across hundreds of channels.

Altogether a severe trial, a crucible from which the FOC satellites emerge certified and ready for space.

Oh, that we humans were similarly tested before placement in positions of power.

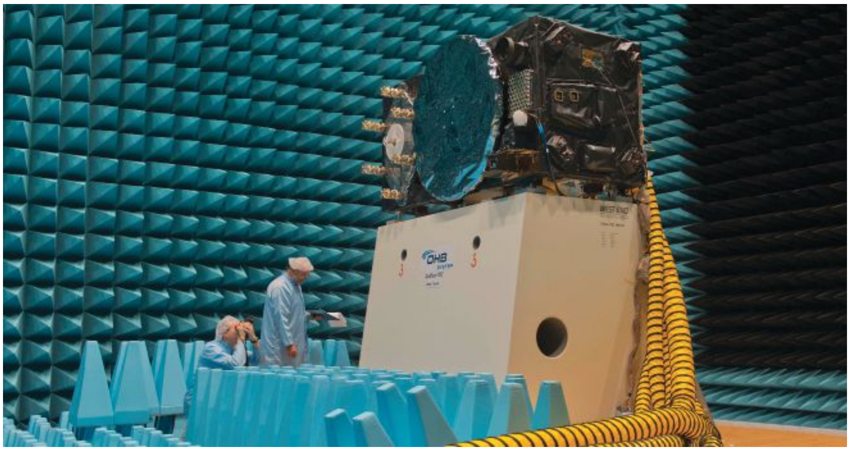

Photo: ESA-Anneke Le Floc'h

INSIDE THE ESTEC TEST CENTER, Galileo's First Operational Capability first flight model, FM1, prepares for passive intermodulation testing in the Maxwell electromagnetic facility.

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Published monthly
NORTH COAST MEDIA LLC
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Land Ho! Uncharted Island Ahead

BY Tracy Cozzens
MANAGING EDITOR

Photo: NASA

A new island near Tonga has officially been surveyed, courtesy of Goddard NASA scientist Dan Slayback. Most new islands vanish as fast as they appear from punishing ocean waves, but this one is different. It's one of only three volcanic islands to live longer than a few months in the past 150 years, and the first survivor since satellites began collecting Earth imagery.

"There's no map of the new land," Dan said. The island, nestled between two older islands, erupted from the rim of an underwater caldera in early 2015. The older islands were on some nautical charts at coarse resolution.

Slayback has been watching the island via satellite since its birth, trying to make a 3D model of its shape and volume as it changes over time to understand how much material has been eroded and what it is made of that makes it partially resistant to erosion. But while high-resolution satellite observations provide some data, nothing beats a visit.

On Oct. 9, 2018, Slayback and students with the Sea Education Association (SEA) measured the location and elevation of boulders and other erosional features visible in the satellite image. Using a high-precision GPS unit with a rover and base station, Dan and the students took about 150 measurements that narrow down each point's location and elevation to better than 10 centimeters. They also used a drone to conduct an aerial survey of the island for another layer of observations to make a high-resolution 3D map.

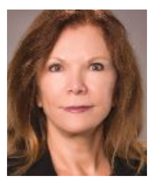
The elevation changes were more dramatic than Slayback expected. The data that the team gathered on the ground will help scientists hone the model they use to convert satellite images to ground heights, according to NASA.

NASA scientists are keen to understand how new islands form and evolve on Earth; the knowledge may provide clues about how volcanic landscapes interacted with water on ancient Mars. 🌐

PNT Q&A — EDITORIAL ADVISORY BOARD

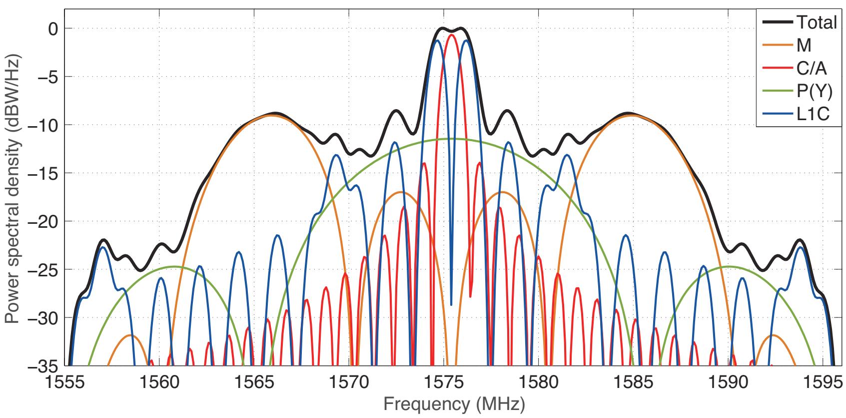
What's the biggest challenge in simulating new GNSS signals for manufacturers' product testing?

"Anyone can follow a spec, but real expertise is required for interpreting nascent ICDs, looking for inconsistencies and pitfalls. The first receivers to market may not always get it right, especially before and during early live-sky signal broadcasts."
— John Fischer, Orolia



"The challenge is twofold. Manufacturers are constantly implementing new signals, which is extremely difficult and expensive to do without the use of a simulator in a lab. The second problem manufacturers are facing is integrating secure signals across international constellations."
— Ellen Hall, Spirent Federal Systems

"The industry has been stimulated by growing constellations and the arrival of new signals, resulting in an increasing number of sophisticated receivers hitting the market. Our biggest challenge is ensuring that all simulated signals work on all of these receivers."
— Julian Thomas, Racelogic Ltd.



All figures provided by the authors.

FIGURE 1 Theoretical spectra of the four signals transmitted by a GPS III satellite in the L1 frequency band.

First Light

Broadcast of L1C by GPS III

BY Peter Steigenberger, Oliver Montenbruck, Steffen Thoelert and Richard Langley

Less than three weeks after its launch, the first GPS III satellite, SVN74, started transmitting navigation signals. SVN74 uses the pseudorandom noise (PRN) code number G04 previously used by the almost 25-year-old Block IIA satellite SVN36. The L1 C/A, L1 P(Y), and L2 P(Y) signals of SVN74 have been tracked since Jan. 9 at 00:01 UTC. Activation of the L2C and L5 signals followed on the same day at 19:43 UTC. Transmission of the legacy navigation message (LNAV) started Jan. 9, but the satellite is still marked unhealthy for ongoing on-orbit check out and testing.

Also, SVN74 is the first GPS satellite to transmit a new civil signal on the L1 frequency (1575.42 MHz), namely L1C, which was initially activated on the same day as the other SVN74 signals. Incidentally, the L1C signal was already being transmitted by the four satellites of the Japanese Quasi-Zenith Satellite System (QZSS).

Compared to the L1 C/A PRN codes, the L1C codes are 10 times longer (10,230 chips), reducing interference when multiple satellites are tracked by a receiver on the same frequency. Like L2C and L5, the L1C signal consists of a dataless pilot component and the data component with navigation data. Dataless signals enable more robust tracking under difficult conditions. For the L1C signal, 75 percent of its power is put into the pilot component.

The theoretical spectra of the four signals transmitted on L1 by SVN74, namely the civil C/A-code and L1C, as well as the military P(Y)-code and M-code, are shown in **FIGURE 1** along with the the total (summed) spectrum.

BOC. To achieve compatibility with the L1 C/A-code signal at the same center frequency, a binary offset carrier (BOC) modulation is used for spectral separation of L1C from L1 C/A. A BOC(n,m) signal is characterized by the fundamental frequency of the square wave subcarrier expressed in multiples n of the basic frequency of 1.023 MHz and the chipping rate expressed in multiples m of 1.023 megachips per second. A BOC(1,1) modulation is used for the L1C data component. For the pilot component, a time-multiplexed binary offset carrier (TMBOC) is used. The spreading waveform, with a length of 33 symbols, consists of four BOC(6,1) and 29 BOC(1,1) symbols as illustrated in **FIGURE 2** resulting in a TMBOC(6,1,4/33) signal. The additional BOC(6,1) component allows for improved multipath mitigation.

Similar to GPS L1C, the European Galileo and the Chinese BeiDou-3 systems employ multiplexed BOC signals with BOC(1,1) and BOC(6,1) components in the L1 frequency band. A composite BOC (CBOC) modulation has been adopted for the Galileo E1 open service signal, which uses a weighted sum of the BOC(1,1) and BOC(6,1) components in both the data and the pilot channels. For the BeiDou B1C signal, BOC(1,1) is used for the data channel, while a quadrature multiplexed BOC modulation, QMBOC(6,1,4/33), with BOC(1,1) and BOC(6,1) subcarriers in phase quadrature, is used for the pilot channel.

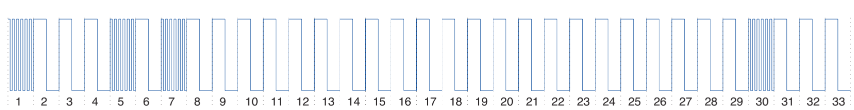


FIGURE 2 Spreading symbols for the L1C pilot component: time-multiplexed BOC consisting of BOC(6,1) for the 1st, 5th, 7th and 30th symbols and BOC(1,1) for the other symbols.

Interoperability. The new civil L1 signals of GPS, Galileo and BeiDou show a high level of commonality and are specifically designed for full interoperability. This means that receivers can easily track signals of all three constellations and use the measurements to compute a combined multi-GNSS position solution. Aside from the similar signal modulations, the interoperability is further supported by the transmission of inter-system timing biases (such as the GPS-Galileo Time Offset) in the navigation messages.

The binary phase shift keying (BPSK) modulation of the C/A-code with a 1.023-MHz chipping rate introduces a main lobe at the center frequency of 1575.42 MHz and numerous side lobes with decreasing amplitude. The 10.23-MHz BPSK signal of the P(Y)-code is visible in Figure 1 as a broad peak at the center frequency and first side lobes at about 1560 and 1590 MHz. The M-code is characterized by its main lobes ±10.23 MHz from the center frequency due to its BOC(10,5) modulation. Finally, the L1C signal can be recognized as two narrow peaks separated by ±1.023 MHz from the L1 center frequency related to the BOC(1,1) modulation and two peaks at ±6.138 MHz related to the BOC(6,1) modulation. Side lobes of the BOC(1,1) signal are visible next to the main lobes at integer multiples of 2 × 1.023 MHz.

Observations. The German Aerospace Center (DLR) operates a 30-meter dish antenna at its ground station in Weilheim, near Munich, Germany. **FIGURE 3** shows the L1 spectrum of SVN74 measured on January 15, 2019. One can clearly see the L1C BOC(1,1) main lobes at 1574 and 1576 MHz as well as the BOC(6,1) main lobes at 1569 and 1581 MHz. Selected side lobes are also indicated.

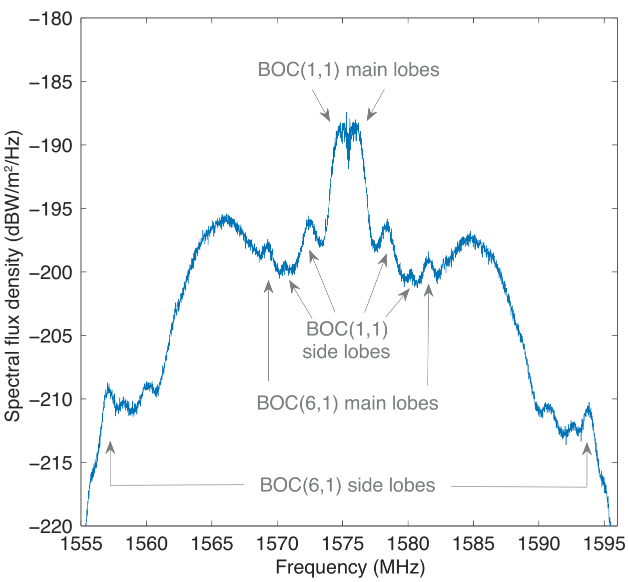


FIGURE 3 SVN74 L1 spectral flux density measured with the Weilheim 30-meter antenna on January 15, 2019, at 08:04 UTC. Selected features of the L1C signal are indicated by arrows.

Initially, none of the International GNSS Service network receivers could track the L1C live signal of SVN74, but dedicated firmware versions supporting L1C tracking were soon made available by selected manufacturers. **FIGURE 4** shows the multipath linear combination for the L1 C/A-code and the L1C signal tracked with a Javad TRE-G3TH receiver. Reduced measurement noise (multipath plus receiver measurement noise) of the L1C signal can be seen over all elevation angles ranging from about 3 to 83 degrees. (Tracking of the pass began at 4.3 degrees and ended at 3.0 degrees.)The overall root-mean-square noise of the SVN74 pass shown in Figure 4 is 32 centimeters for the L1 C/A-code signal and 24 centimeters for L1C, that is, a reduction of 25 percent for L1C. Compared to the BPSK modulation of the legacy C/A-code signal, the increased steepness of the TMBOC correlation function offers lower measurement noise for the L1C tracking. In addition, the sensitivity to multipath is reduced.

CNAV-2. Together with L1C, the second version of the civil navigation message, namely CNAV-2, is being transmitted. CNAV-2 is composed of three subframes: subframe 1 contains information about the current epoch. Subframe 2 comprises clock and ephemeris data including inter-signal corrections (ISCs). ISCs provide clock corrections for single-frequency users and dual-frequency users utilizing signals other than L1 P(Y) and L2 P(Y). Whereas the essential broadcast ephemeris data in subframe 2 repeat continuously over the validity period of typically two hours, subframe 3 contains pages with alternating content as listed in **TABLE 1** (page 41). Despite a different message layout, most CNAV-2 parameters and their values match those transmitted in the CNAV message of the L2C and L5 signals. Additional parameters comprise the ISCs for the L1C signal. Compared to the LNAV legacy navigation message, CNAV and CNAV-2 utilize an extended set of

See **FIRST LIGHT**, *page 37.*

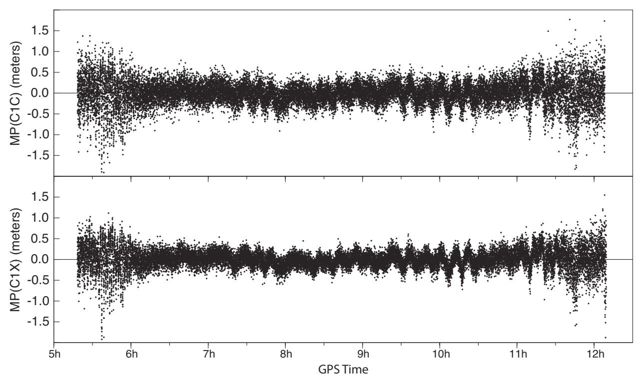


FIGURE 4 Multipath linear combination (L1 pseudorange and L1 and L2 carrier phase) of the SVN74 L1 C/A-code (top) and L1C signal (bottom) from 1-Hz data of February 3, 2019, tracked with a Javad TRE-G3TH receiver at the Geodetic Observatory Wettzell.

②

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1. MEMS INS/GPS

UPDATE IMPROVES HEADING PERFORMANCE AND REDUCES JITTER

The SDN500 digital quartz micro-electro-mechanical systems (MEMS) GPS inertial navigation system (GPS/INS) has been updated. Model SDN500-xE provides a newer generation JF2 (C/A) code GPS receiver and tightly couples the 1 PPS GPS signal to the SDI505 IMU synch pulse to improve heading performance and reduce jitter after long periods of operation without dynamic inputs. The 25-inch-square SDN500 provides for maximum packaging flexibility in dense systems and delivers accuracies to within 1.0 mrad in attitude, 0.1 m/s in velocity and 3.9 meters spherical error probability (SEP). It offers tactical-grade performance, integrating SDI's latest quartz gyros capable of 0.5°/hr. bias in-run stability and low angular random walk (ARW, 0.02°/√ hr), quartz accelerometers delivering 0.5 milli-g in-run bias stability and low velocity random walk (VRW, 80 µg/√ Hz), plus high-speed digital signal into a tightly coupled GPS/INS for tactical navigation and geo-location applications.
Systron Donner Inertial, www.systron.com

2. A-GNSS ANTENNA TESTING

TESTING LOCATION ACCURACY PERFORMANCE OF MOBILE DEVICES

To create test concepts for over-the-air (OTA) antenna measurements, Rohde & Schwarz and Bluetest have integrated the R&S LBS Server, a software component running on the R&S CMW500 wideband radio communication tester, and the Bluetest over-the-air (OTA) test solution for A-GNSS systems based on Bluetest's RTS65 reverberation chamber and Bluetest's Flow measurement software. The R&S LBS Server controls the Rohde & Schwarz base-station simulator R&S CMW500 for LTE, WCDMA and GSM, and uses the R&S SMBV100B vector signal generator for simulation of GNSS and metropolitan beacon systems (MBS) signals. An upgrade for 5G will be available soon. The R&S LBS Server is an essential part of the R&S TS8991 OTA Performance Test System.
Rohde & Schwarz, rohde-schwarz.com
Bluetest, bluetest.se

3. FOG-BASED IMU

BRINGS NAVSIGHT TECHNOLOGY TO THE MOST DEMANDING ENVIRONMENTS

The Horizon IMU adds a third choice to SBG System's Navsight Land/Air Solution. It is a FOG-based high-performance inertial measurement unit (IMU) designed for highly demanding surveying applications such as high-altitude data collection or mobile mapping in dense areas such as urban canyons. The Horizon IMU joins the Ekinox and Apogee IMUs as options for Navsight. The different levels of accuracy enable the solution to meet various application requirements and can be connected to various external equipment such as odometer, lidar and more. The Horizon IMU allows customers to use Navsight in high-altitude and highly dense areas, as well as where only a single antenna can be used. It is based on closed-loop FOG technology that enables ultra-low bias and noise levels. The Navsight solution can be installed in a plane or car — the sensor alignment and lever arms are automatically estimated and validated. The Navsight unit also integrates LED indicators for satellite availability, real-time kinematic (RTK) corrections and power. Qinertia post-processing software provides access to offline RTK corrections from more than 7,000 base stations in 164 countries.
SBG Systems, www.sbg-systems.com

4. DUAL-BAND ANTENNA

FOR MOBILE AND FIXED DEPLOYMENTS

The Coach 4×4 Wi-Fi/DSRC GNSS multi-band antenna enables smart grids, mobile workforce communications, and advanced automation technologies. The dual-band 802.11ac/p MIMO antenna helps boost data rates and reliability for utility networks, intelligent transportation systems and other industrial internet of things (IoT) applications. The low-profile antenna features four-port 2.4/5-GHz coverage along with PCTEL's high-rejection GPS/GLONASS technology for network timing and tracking in a single IP67-rated housing.
PCTEL, www.pctel.com


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Artists' renderings: Lockheed Martin and Boeing Co.

THAT WAS THEN. THIS IS NOW.

WHEN MANAGED BY A NEW GROUND CONTROL SYSTEM, GPS III SATELLITES will offer triple the accuracy and eight times the anti-jamming capabilities of the satellites currently comprising the U.S. Air Force's GPS constellation. Users military and civilian will reap ample benefits.

BY ALAN CAMERON

Everything changed for space-based positioning, navigation and timing around the world on Dec. 23, 2018. Or maybe it didn't. The innovations heralded by the launch of the first GPS III satellite will take years more to occur. We tabulate here the advances that Generation Three will bring over GPS-to-date, and review the timeline for their actual arrival.

While these new capabilities exist — in concept — in space, they can't be leveraged on the ground (or in the air, or at sea) until a sufficient number of additional GPS III satellites have joined the constellation, and until a new ground control system comes online. This will occur — perhaps — in 2023. At that time the satellites' talents will be unleashed.

"As more GPS III satellites join the constellation, it will bring better service at a lower cost to a technology that is now fully woven into the fabric of any modern civilization," stated Lt. Gen. John Thompson, commander of the U.S. Air Force's Space and Missile Systems Center and the Air Force's program executive officer for space.

The many GPS III upgrades should make the service more reliable and accurate for civilians, more secure against those who want to jam military users, and more cyber-secure for everyone.

TALKIN' 'BOUT OUR GENERATION

GPS constellations have grown through six major iterations since 1978. The sixth, GPS IIF, rose during the years 2010 to 2016. Those 12 satellites are all designed to last 12 years. Some of their notable features include the ability to receive software uploads, better jamming resistance and increased accuracy.

GPS III, the seventh generation, will launch nine

All GNSS civilian signals

TRIUMPH 3

Based on TRIUMPH chip with 864 channels

• Spread Spectrum • Bluetooth • UHF • 4G/LTE Cellular • Wi-Fi • Integrated GNSS antenna

see back page >

J-Mate Overview

6 pages inside >

J-Mate Test Volunteer

We have delayed the introduction of the new J-Mate to enable us to add new features like replacing liquid vials with a highly accurate internal inclinometer to monitor and continuously compensate for level offsets.

We now are ready to send J-Mates to **20 volunteers in the United States**, who would like to test the J-Mate with their TRIUMPH-LS and give us feedback over a period of up to two months.

As a reward for each volunteer's efforts, we will offer a **50% discount on the J-Mate** if they decide to buy it.

Please go to **www.javad.com**, to submit your volunteer application at "J-Mate Test Volunteer".

JAVAD

J-Mate Quick Overview and Update to Videos

First let's set the record straight: J-Mate is not a total-station. J-Mate and TRIUMPH-LS **together** are a **"Total Solution"** which is a combination of GNSS, encoder and laser range measurements that **together** does a lot more than a total station. At long distances you use GNSS and at short distances (maximum of 100 meters) you use the J-Mate along with the TRIUMPH-LS. Together they provide RTK level accuracy (few centimeters) in ranges **from zero to infinity**. Although the sensors are specified to work up to 100 meters, usage is quicker and more convenient for distances of up to 50 meters.

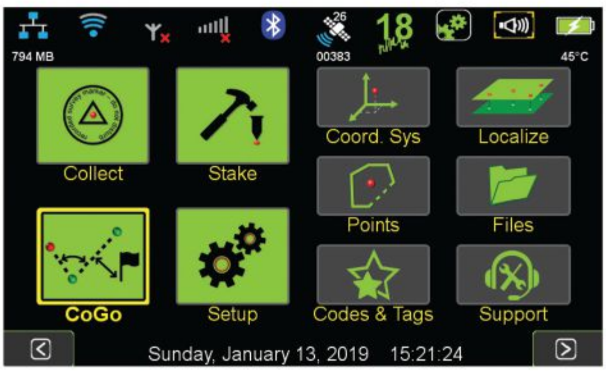
One burden that we leave you with is to focus the camera manually when you need it. If you are always more than 15 meters away from the target, you keep the focus button on maximum and leave it there. We will replace the focus button to make it easier to access if needed.

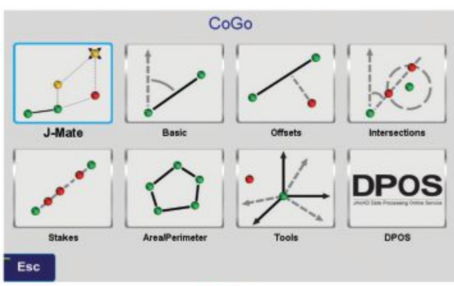
As with the TRIUMPH-LS, with the J-Mate we also provide software improvement updates regularly and free of charge. Download the J-Mate update in your TRIUMPH-LS and then inject it to the J-Mate. When you connect the TRIUMPH-LS to the J-Mate, the injection will be done automatically; but with your consent.

There are many new features in the J-Mate. We try to explain them in a few steps. Please also view the J-Mate videos on our website.

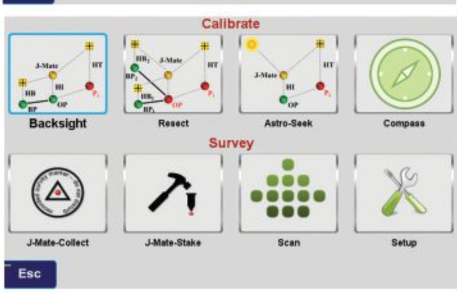
Connecting J-Mate to TRIUMPH-LS:

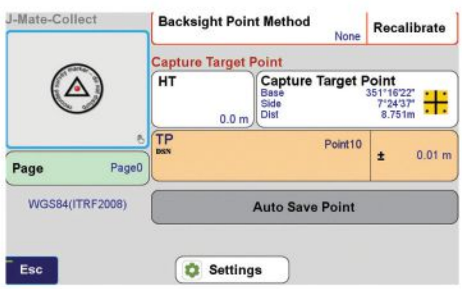
TRIUMPH-LS communicates with the J-Mate through Wi-Fi. Turn on both the TRIUMPH-LS and the J-Mate. Click the Wi-Fi icon of the TRIUMPH-LS Home screen to connect to the J-Mate, much the same way as you connect TRIUMPH-LS to your Wi-Fi access point. J-Mate has ID of the form JMatexxx.





After connection, try to get acquainted with the **Main Navigation Screen**: On the TRIUMPH-LS Home screen, click CoGo/J-Mate/J-Mate Collect/Capture Target points.





Finding the target automatically:

There are three ways to search and find the target automatically:

1) One is by laser to scan and snap to a point when range changes by the specific amount. This is particularly valuable to snap to cables, poles and edges of buildings.

2) Second is search for the object of the specific flat size and focus on its center.

3) Third is with the camera to search for the QR target that we supply. We will discuss these later.

Switching between the two cameras:

You can view the scenes by the wide-angle camera of TRIUMPH-LS, while sitting on top of J-Mate; or by the narrow angle precise camera on the Side of J-Mate. Click Button **“4”** of Figure 1 to switch between the two.

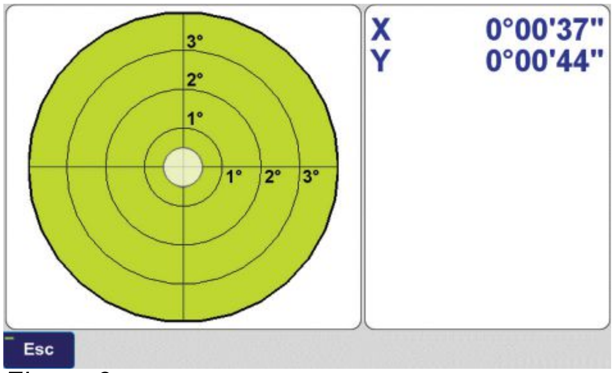


Figure 3

Viewing the embedded Inclinometer:

If you hold button **“4” of Figure 1**, you will see the embedded 0.001-degree electronic inclinometer of the J-Mate as shown in Figure 3. It updates 10 times per second.

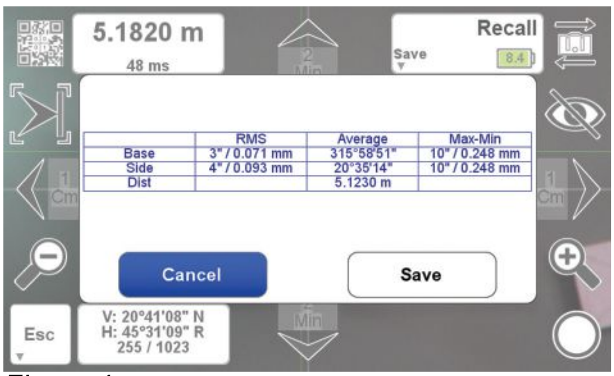


Figure 4

Taking a Point:

When you focus on your target manually or automatically, you can click the “Take” button (**“5”** in the Figure 1). The Encoders will be measured 10 times, the average, RMS and spread will be shown and you can decide to accept or reject (Figure 4). The accepted points will be treated like RTK points but labelled as “JM” points.

You can access and treat them like any other points in the TRIUMPH-LS.

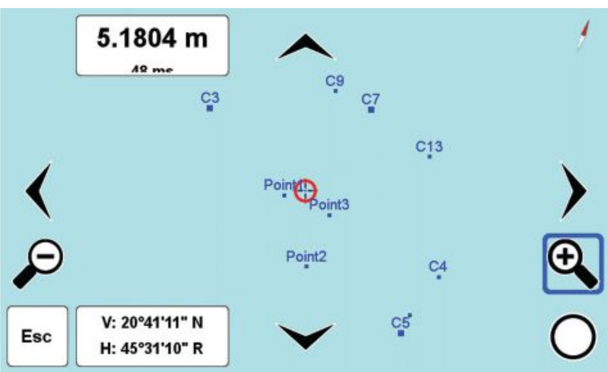


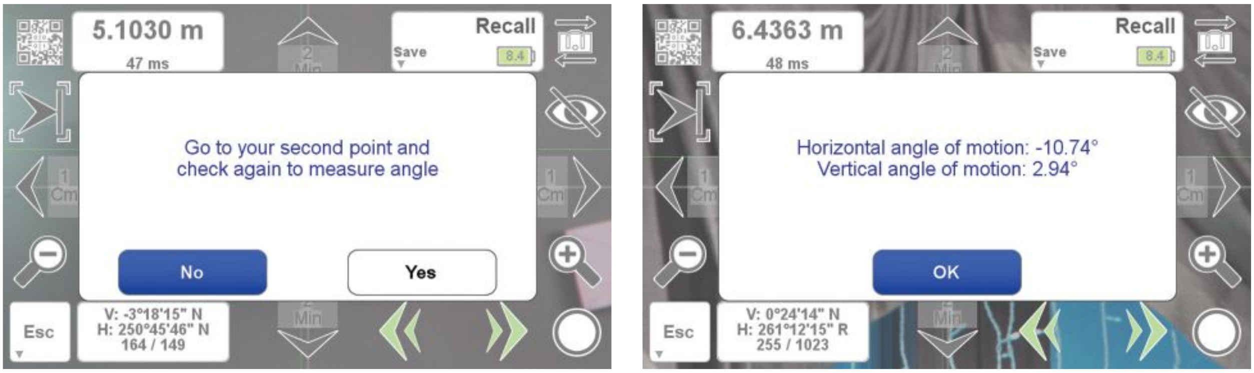
Figure 5

Viewing the Measured Points:

Clicking button **“6”** in Figure 1 will remove some of the items from the screen (Figure 5). Hold it long and you will see live view of the points taken by J-Mate.

Measuring angles quickly:

Aim at the first point and click button **“7”** of Figure 1. Then Aim to the second point and click this button again. You will see the horizontal angles between the two points.



Saving and Recalling Orientations:

Aim at a point and hold long the button **“8”** of the Figure 1 to save the horizontal, vertical, or both of that orientation (Figure 7). Click this button to rotate to that saved orientation.

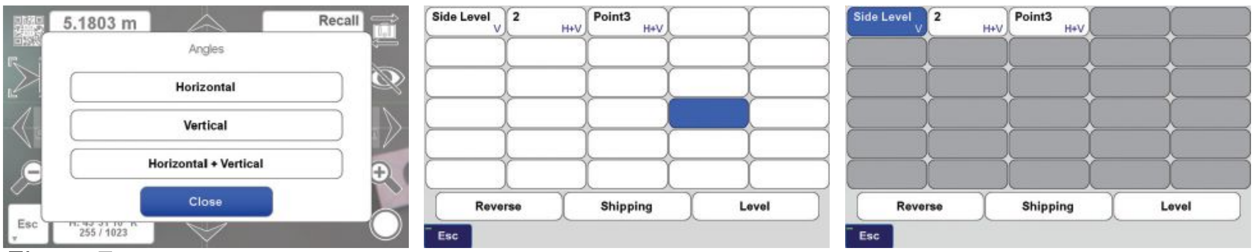
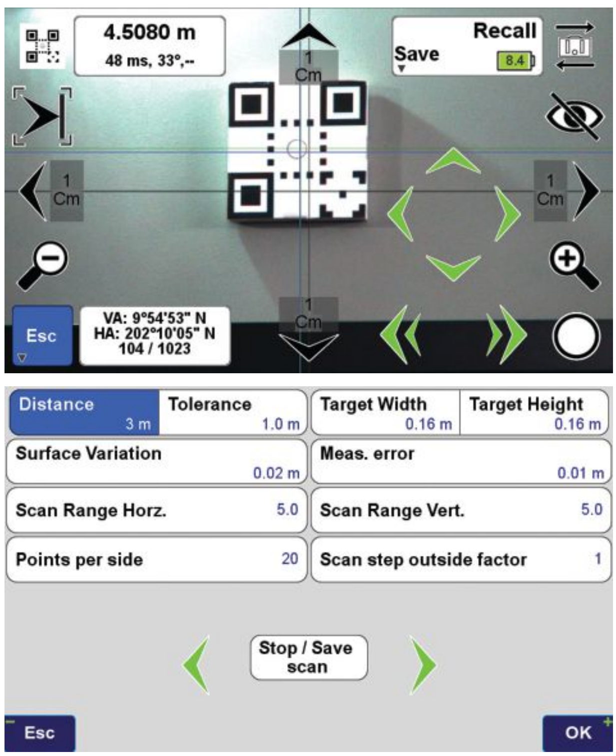


Figure 7

Scanning and Snapping to an object:



Click button **“9”** of Figure 1 and the left and right motion buttons (**“3”** on Figure 1) change to red which means when you click them scanning to snap will start. Hold long button 9 to get to the screen that sets the parameters for the Scan and Snap operation.

In this screen you can define the scan range and ask the scan to stop when range changes by the specified value. Then you can select the point that was measured before the stop or after the stop. By selecting a very large number you can scan the ranges that you have specified and record the 3D image. When you click button 9 to stop change the scanning back to normal motion, you will be asked if you want to save the scanned file. You can view the 3D image of the scanned file in the “File” icon of the Home screen of the TRIUMPH-LS.

Connecting and Re-connecting J-Mate to TRIUMPH-LS

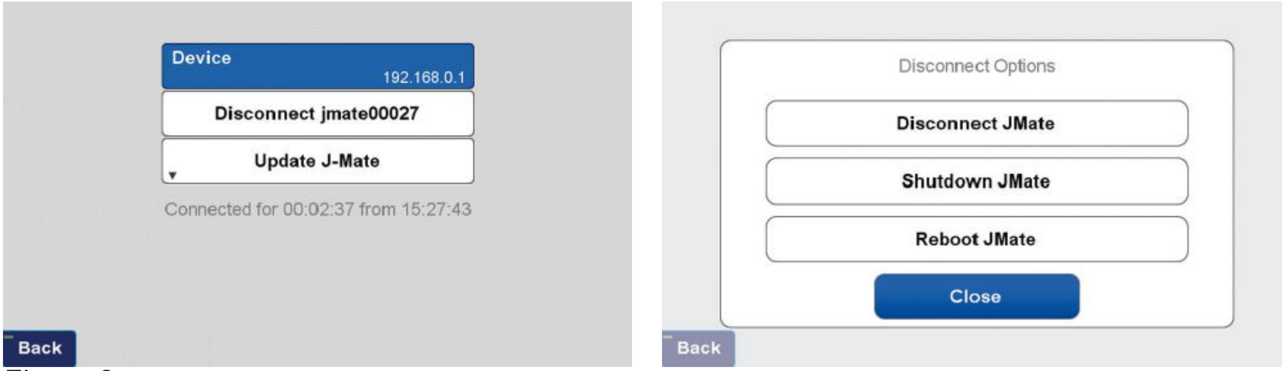


Figure 8

Holding the **"ESC"** button (**"10"** in Figure 1) will take you to Figure 8 which lets you disconnect J-Mate, Reboot, or turn off. Like all Wi-Fi connections, you may lose connection and need to use this screen to disconnect, re-connect, or re-boot J-Mate and in some occasions reboot TRIUMPH-LS too, especially when connection between the camera of the J-Mate and TRIUMPH-LS is lost.

View Range measurements

Box **"12"** of the Figure 1 shows the range measurements. It reads up to 20 times per second.

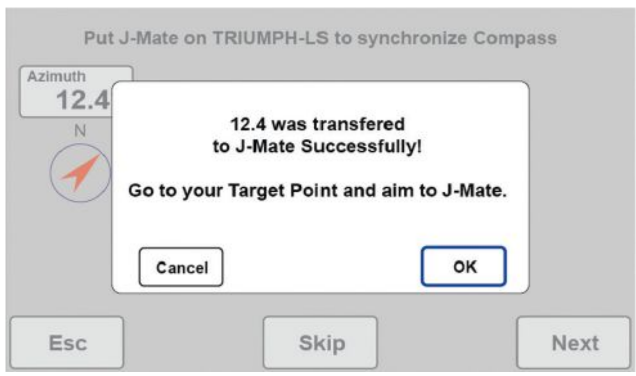
Automatic Finding of the Target:

Click the QR icon (**"11"** of the Figure 1). You will be guided through the following steps to aim at your target point. :

1. Put the TRIUMPH-LS on top of J-Mate (or slightly above it, but at the same orientation as the J-Mate, to be far from the motor magnets of the J-Mate) and click Next.

This step will transfer the compass reading of the TRIUMPH-LS to the J-Mate encoders.

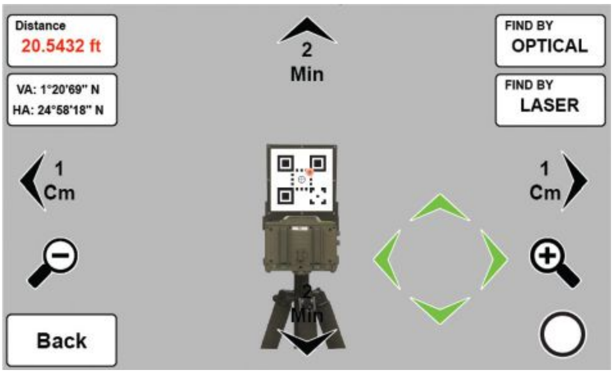
You can skip this and the next step if you are in an area that the compass readings are not valid or you can aim manually in the next steps. .



2. Go to your target, Put the QR accessory on top of the TRIUMPH-LS and aim the TRIUMPH-LS towards the J-Mate (with the help of the TRIUMPH-LS camera) and click Next.

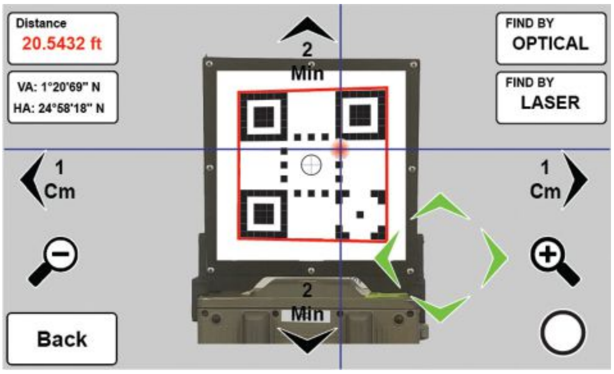
This will help the J-Mate to know the general direction to the target and limit its search range. You can go back to previous step to fine tune view of the J-Mate. Or you can skip these two steps.

3. You will see the J-Mate camera view on the TRIUMPH-LS screen. You can fine tune the J-Mate view by the navigation buttons to make recognition faster. You can skip these steps if you don't want to make the search faster.



In here you can also manually aim at the center of the QR panel and take your shot.

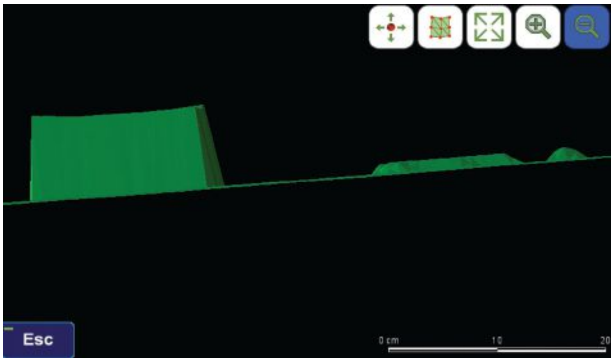
4. Click "Find by Optical" if you want the QR panel to be scanned and centered automatically.



When J-Mate focuses on the center of the QR, you can click the "Take" button. You will be asked if you want to record the point.

5. If you also want to find the center of the QR by Laser scanning, you can click the "Find by Laser". If Laser scan is successful, you can click the "Take" button to replace the previous measurement with the current measurement done by laser scanning.

The center of the QR is vertically collocated with the GNSS antenna and you don't need to be exactly perpendicular to the J-Mate path. For safeguard, we measure the four sides of the QR and determine the angular offset, if we need it.

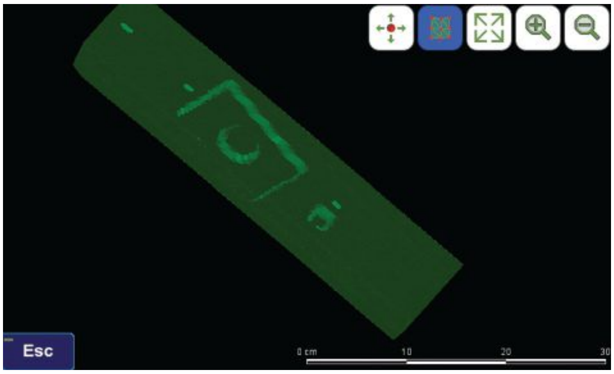


If light condition is such that camera cannot find the QR, chances are better that laser scanner can find it.

Finding the center of QR by laser and by the camera is a tool to calibrate these two sensors together.

You can run this feature periodically to re-calibrate their axis if you need to. This calibration is small portion of the factory calibration.

You see the 3 views of the 3D scanning



The first scan image is scan of a 1 cm thick and a 6 cm thick objects. 1 cm step resolution.

The last one is scan of a 12.5 x 8 cm object of 1 cm thickness.

This overview as also an update to videos at www.javad.com.

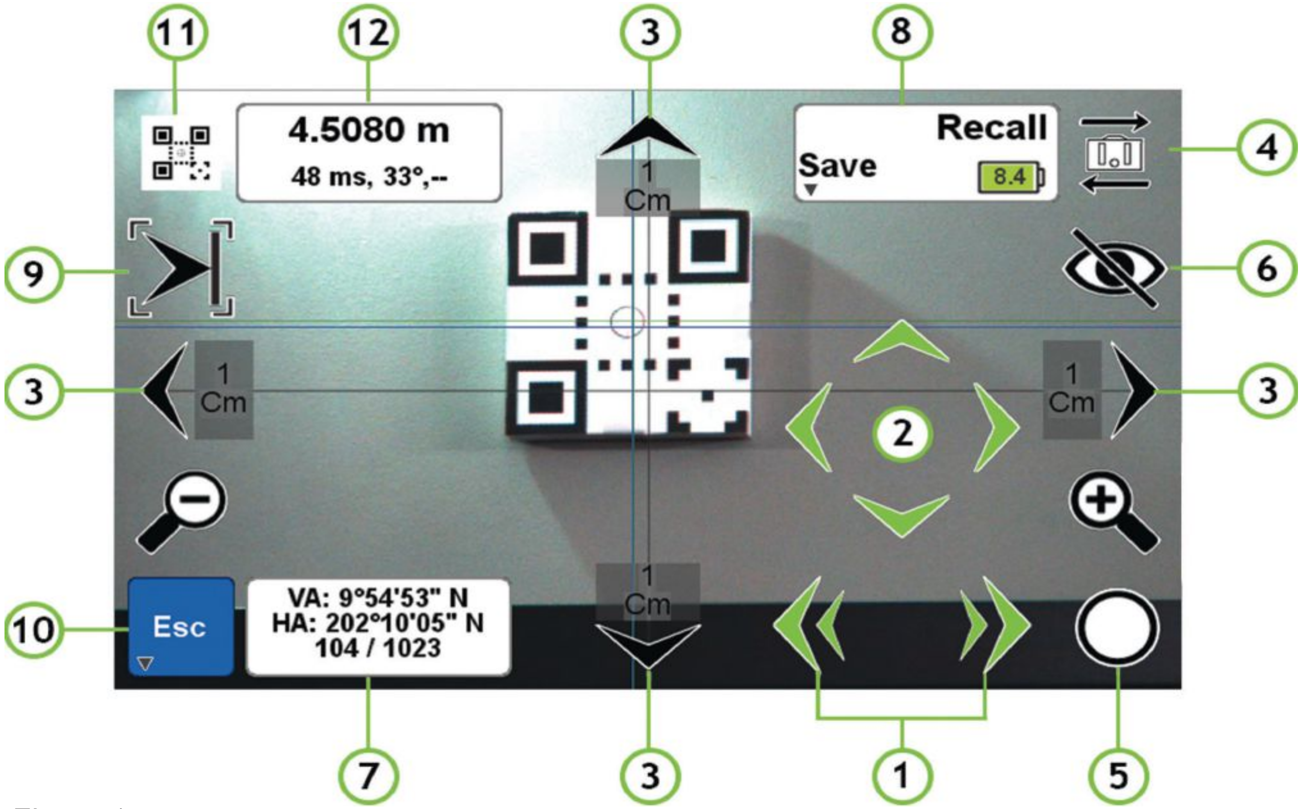


Figure 1

This is the **Main Navigation Screen**

Finding the Target:

You can find targets manually or automatically.

There are five ways that you can manually rotate the J-Mate towards your target:

1. On the bottom right of the Main View screen, there are left and right "Fast Motion" buttons. While you hold them the J-Mate rotates about 30 degrees per second. (**"1"** on the Figure 1)

2. Above them, there are slow Left/Right/UP/Down "Slow Motion" buttons. While you hold them, the J-Mate rotates about 5 degrees per second. (**"2"** on the Figure 1)

3. Then there are Left/Right/Up/Down buttons around the screen. Each click moves the J-Mate according to the value that users assign to them. Hold these buttons to assign angular or linear values to them (**"3"** on the Figure 1). The Value Assignment Screen is shown in Figure 2.

Figure 2

4. Touching points on the cameras and by gestures.

5. You can also rotate the J-Mate manually while it is not moving automatically, but limit that to the small rotations in the area of motor free motion, not to apply backpressure to motor as much as you can. Motor manufacturer does not prohibit manual motion, but we think it is better to avoid that as much as possible.

TRIUMPH-3

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

Based on our new third generation a 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, as a Continuously Operating Reference Station (CORS), 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 2.4GHz (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

more satellites to join SV01 already in space. GPS III SV02 is scheduled to launch in July of this year, SV03 in late 2019, and SV04 in 2020. The final III payload should rise in 2023. From that point on, the follow-on era of GPS IIIF takes over.

How Long, How Long? "Projections for how long the current constellation will [continue to] be fully capable have increased by nearly two years to June 2021, affording some buffer to offset any additional satellite delays," reported the Government Accounting Office at the end of 2017. This provided some schedule buffer for launching the first GPS III satellite, but it did not reduce the desire to launch as soon as the booster rocket became available.

The new birds will introduce new capabilities to meet higher demands of both military and civilian users: once filled out, the GPS III constellation will bring three times better accuracy and up to eight times improved anti-jamming capabilities. Spacecraft life requirement will extend to 15 years, 25 percent longer than the latest GPS satellites and twice the original design life of the oldest satellites on orbit today.

The new L1C civil signal broadcast by GPS III is an interoperable signal with other international global navigation satellite systems, like Galileo, improving connectivity for civilian users.

GPS III will eventually actualize full M-code capability — carried aboard the IIR-Ms and IIFs but not yet completely implemented — in support of warfighter operations. GPS III M-code capability exceeds that of GPS IIR-M and GPS IIF.

GPS III will complete the deployment of the L2C civil signal and the L5 safety-of-life signal capabilities that began with \GPS IIR-M and GPS IIF satellites.

Finally, GPS III will enact improved integrity: the ability of the satellite to detect and issue alerts on its own reduced accuracy, should that phenomenon ever occur.

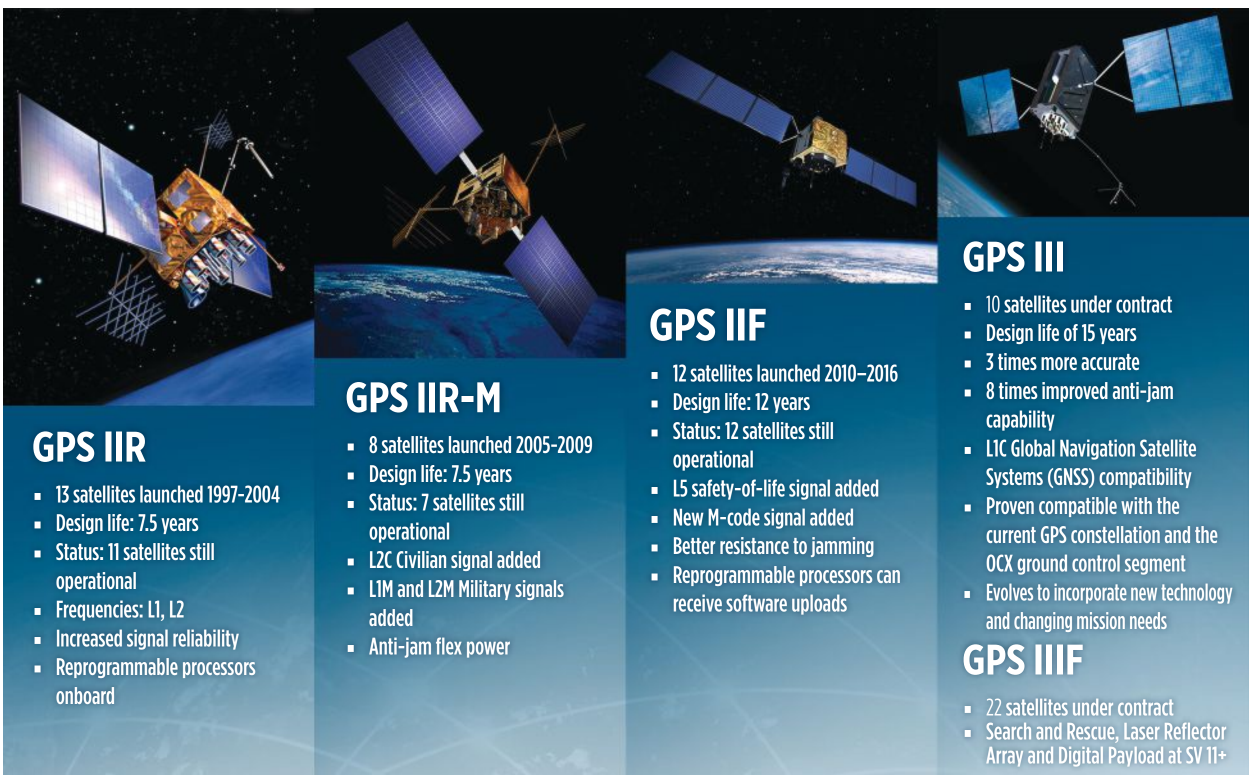
Military Signal Power Up. Encrypted M-code signals will be up to eight times more powerful than currently. This makes them more reliable. but also enables the sats to overcome efforts to jam their signals.

Other signals also offer increased signal power at the Earth's surface. L1 and L2: –158.5 dBW for aC/A code signal and –161.5 dBW for the P(Y) code signal. L5 will be –154 dBW.

STORY OF L

L2C, the second open GPS signal, after L1 C/A, has been available from every new GPS satellite since the first IIR-M launch in 2005. L5, the third open GPS signal, became available with the first IIF launch in 2010. Now L1C, the fourth open GPS signal, joins the band, broadcasting from every new GPS satellite, starting with the recent GPS III launch (see "First Light," page 12).

The first GPS III satellite is in



Graphic sourced from: Lockheed Martin and Boeing Co.

FAMILY FEATURES. The most recent generations of the GPS constellation. IIR, IIR-M and III were produced by Lockheed Martin, while IIF was built by Boeing. One GPS IIA satellite is still in operation, at 25 years young (design life was 7.5 years). All satellites carry Harris Corporation payloads.

Photo: Lockheed Martin

THE FIRST GPS III satellite was fully assembled and entered into SV single-line flow when Lockheed Martin technicians integrated its system module, propulsion core and antenna deck.

checkout and testing that could last up to 18 months before it enters service. "After its Dec. 23 launch, GPS III SV01 successfully completed its orbit raising and deployment of all of its antennas and solar arrays. On Jan. 8, the satellite's navigation payload began broadcasting navigation signals," said Johnathon Caldwell, Lockheed Martin vice president for navigation systems. "On-orbit testing continues, but the navigation payload's capabilities have exceeded expectations and the satellite is operating completely healthy."

Testing, Testing. Using the Air Force's Back-to-Basics program, which involved early prototyping and simulations, Lockheed Martin developed GPS III with an approach that involved rigorous quality-build certificates, component testing and system-level testing. The comprehensive requirements verification and validation process ensured more than 30,000 requirements were achieved. The system functional qualification includes the performance verification in multiple environmental tests, including the acoustic, thermal vacuum (TVAC) and electromagnetic spectrum.

"We consider thermal vacuum the gold standard for testing any satellite before it goes into operations," Col. Steve Whitney, director, GPS Directorate, wrote in *GPS World* in December. "It really is putting the craft through the paces. When it goes through the testing, the satellite is on. It is working. It is exposing it to the heat and the cold and the zero pressure while the satellite is functional. The entire thermal vac testing from start to end is about 70 days. Test like you fly. From the time it launches and deployment sequence, we test it like it is real. Minus the shaking, the satellite thinks it is getting launched. Meanwhile, our people are looking at the data and its health. TVAC is a huge milestone for a satellite to go through and come out no issues."

To date, more than 90 percent of parts and materials for all 10 GPS III satellites have been received from more than 250 aerospace companies in 29 states.

BRAIN OF THE BUNCH

Harris Corporation is a sub-contractor to Lockheed Martin for development and production of GPS III Mission Data Units (MDUs) and transmitters for the GPS space section. Six have been delivered.

The Harris MDU, together with the Atomic Frequency Standards and the L-band transmitter equipment, make up the Navigation Payload Element. The MDU performs the primary mission of the GPS satellite: generation of the navigation signals and data on a continuous basis. The MDU controls the generation of the precise timing signals used for navigation signals while distributing the timing signals to other satellite components.

This MDU is 70 percent digital. The next to come, aboard GPS IIIF satellites, will be fully digital.

When asked about the advantages of an all-digital payload, Harris Corporation's Jason Hendrix, PNT program director, told *GPS World* in April 2018, "The advantages and the 30 percent difference are the timekeeping system portion. We're moving from manual, analog timing to digital to deliver to the Air Force more flexibility. It's a nice option to have to be able to reprogram in orbit and maybe enhance capabilities desired in the future."

LIVING BETTER, LIVING LONGER

Greater mission longevity is one of the key improvements GPS III delivers over those currently in service. Space Vehicles 1–10 have a planned mission life of 15 years, 25 percent longer than their predecessors. That begs the question, "How long should a satellite live in space, with technology innovation occurring almost annually?"

Advanced payload technology provides a partial answer. Lockheed Martin and Harris point to new payload capabilities with built-in flexibility to adapt satellites in orbit to technology advances, as well as changes in missions. According to Harris, the fully digital navigation payload will provide the ability to change and upgrade the satellites incrementally over mission life.

In late 2017, Lockheed announced a partnership with NEC Corporation to introduce artificial intelligence for computer learning in orbit. The company touted significant advances in processers and a move toward next-generation antennas, arrays and transmitters to drive more satellite flexibility, capability and resilience.

FROM THE GROUND UP

GPS III's military upgrades require new ground control stations, a replacement effort called OCX that has suffered repeated delays and cost increases, due to the complexity of the programming and requirements modifications. The new jamming-resistant military signal will not be available until the new, highly complex ground control system is available, and that is not expected until 2022 or 2023. Delay and cost considerations were driven in part by full implementation of all Department of Defense 8500.2 "Defense in Depth" information assurance standards without waivers, giving it the highest level of cybersecurity protections of any DoD space system.

Deliverables for GPS OCX are divided into three blocks. Block 0 delivery took place in fall 2017, enabling it to support the December launch. Block 1 delivery will take place in 2021, providing full operational capability to control both legacy and modernized satellites and signals. Block 2, delivered concurrently with Block 1, adds operational control of L1C and modernized M-code.

In 2018, wrote Col. Whitney of the GPS Directorate, "We have actively utilized the [Block 0] system in a variety of exercises, training events, compatibility tests and launch readiness events. We also completed a comprehensive security review of the system to demonstrate our readiness to start operations. The system is ready to go. We continue to work the development of the OCX Block 1 system and are wrapping up the initial coding of the system early in 2019, leading into our integration and test campaign."

Given delays in OCX, "the Directorate is actively working two major upgrades to bridge the gap," Whitney continued. "The first is GPS III Contingency Operations (COps) modification which will allow the 2nd Space Operations Squadron (2SOPS) to command and control the GPS III family of vehicles in a mission state matching today's legacy signals for all users world-wide. The second modification is M-code early use (MCUE), which enables 2 SOPS to operationalize the Modernized GPS military (M-code) navigation signals for the warfighter."

Before December's launch, OCX underwent rigorous cybersecurity vulnerability assessments that tested the system's ability to defend against both internal and external cyber threats. GPS OCX prevented the broadcast of corrupt navigation and timing data in all tests, bolstering the program's readiness for GPS III.

"We've built a layered defense and implemented all information assurance requirements for the program into this system," said Dave Wajsgras, president of Raytheon Intelligence, Information and Services. "The cyber threat will always change, so we've built OCX to evolve and to make sure it's always operating at this level of protection."

The new Harris navigation payload offers a smooth transition to use of OCX. The payload for the first 10 GPS III satellites has been verified for OCX compatibility so the same OCX commands will seamlessly port to the Harris fully digital design, minimizing integration risks and associated costs.


Artist rendering: Lockheed Martin

GPS IIIF'S M-CODE can be broadcast from a high-gain directional antenna in a concentrated, high-powered spot beam, in addition to a wide-angle, full-Earth antenna.

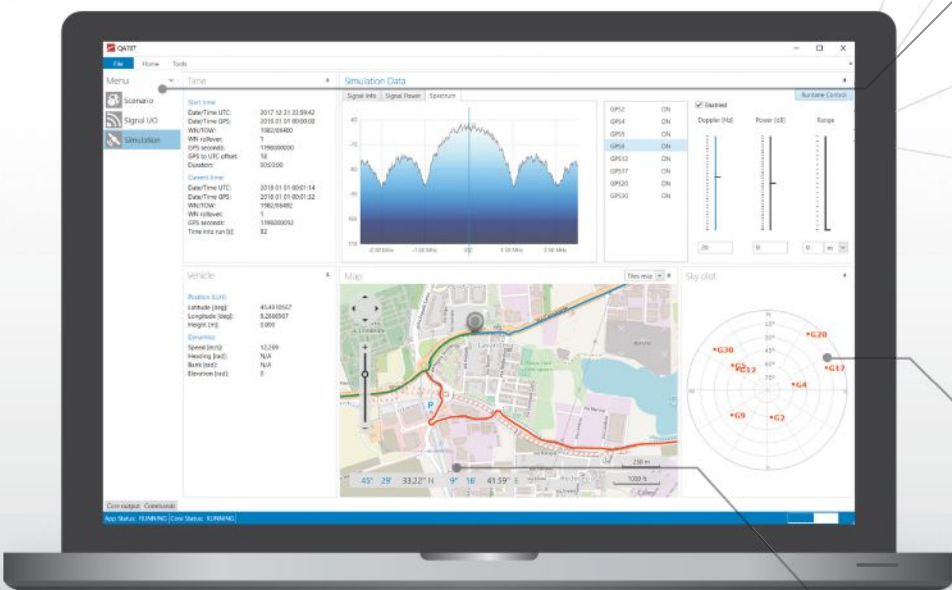
According the the GAO, "Full M-code capability — which includes both the ability to broadcast a signal via satellites and a ground system and user equipment to receive the signal — will take at least a decade once the services are able to deploy military GPS user equipment (MGUE) receivers in sufficient numbers." The April 2019 issue of *GPS World* will review M-code implementation across U.S. DoD platforms.

THE FUTURE'S NOT OVER YET

In spring 2018, Lockheed Martin submitted a proposal for the GPS III Follow On (GPS IIIF) program, which will add enhanced capabilities to the satellites. New hardware — a high-gain directional antenna — aims signals in a spot beam at a limited area, but blasts the signal at high power for strategic use by the military.

Inter-Satellite Links. Block IIIF satellites will carry laser retro-reflectors to enable orbit tracking independently of the satellites' radio signals, which in turn will allow satellite clock errors to be disentangled from ephemeris errors. A standard feature of GLONASS, this is included in the Galileo positioning system, and was flown as an experiment on two older GPS satellites, 35 and 36.

In September 2018, the Air Force selected Lockheed Martin to build up to 22 additional satellites under the GPS IIIF program.



2019 SIMULATOR BUYERS GUIDE

***GPS World*'s 8th annual Simulator Buyers Guide features tools, devices and software from leading providers.**

CAST NAVIGATION

CAST-5000 GPS WAVEFRONT GENERATOR

The **CAST-5000** produces a single coherent wavefront of GPS RF signals to provide repeatable testing in the laboratory environment or anechoic chamber. The basic system generates four independent, coherent simulations that reference a single point and is upgradeable to support seven elements for CRPA testing. With an intercard carrier-phase error of less than 1 millimeter, the CAST-5000 is extremely accurate.

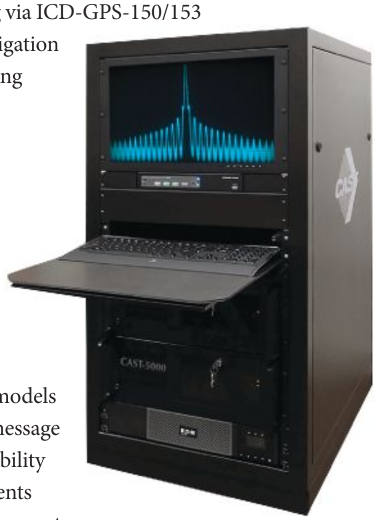
The system generates a wavefront of GPS when its GPS RF generator cards are operated in a ganged configuration. Each generator card provides a set of GPS satellites coherent with the overall configuration. Several RF generator cards may be utilized together, ensuring phase coherence among the bank of signal generator cards.

The CAST-5000 Controlled Reception Pattern Antenna (CRPA) tester allows a full end-to-end test of the antenna system. The CRPA antenna, antenna electronics and the GPS receiver can be tested as a unit with or without radiating signals.

The **CAST-8000** is a new simulator that merges both the CAST-5000 CRPA tester with a CAST-3000 EGI tester.

CAST-5000 Features

- Generates single coherent wavefront of GPS
- 6-DOF motion generation capability
- Complete SV constellation editing
- Post-mission processing via ICD-GPS-150/153
- Differential/relative navigation
- Antenna pattern modeling
- Waypoint navigation
- RAIM events
- Multipath modeling
- Spoofer simulation
- Satellite clock errors
- External trajectory input
- External ephemeris and almanac
- Several iono and tropo models
- Modifiable navigation message
- Modeled selective availability
- Time-tagged satellite events
- Selectable host vehicle parameters
- Directional jamming



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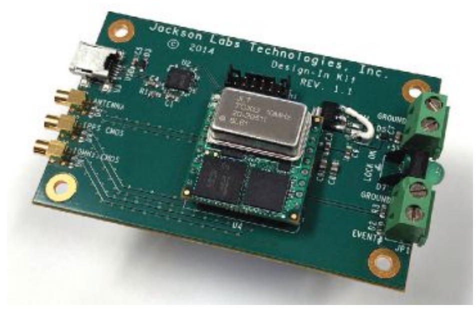

JACKSON LABS TECHNOLOGIES INC.

MICRO-TRANSCODER GPS SIMULATOR/RF-MODULATOR

The tiny 1-inch square Micro-Transcoder module allows glueless retrofitting of existing GPS equipment with secure and Assured-PNT (A-PNT) capability. It is the smallest, full-constellation, stand-alone, real-time 10-channel GPS simulator available from JLT. The unit is useful in upgrading existing legacy GPS receivers with external position, navigation and timing references such as INS, CSAC, SAASM, M-code, GNSS, eLoran or other alternative positioning and timing sources by simply replacing the legacy GPS antenna from an existing GPS system with the Micro-Transcoder RF output.

The unit is based on the JLT CLAW GPS Simulator and RSR Transcoder technologies, and includes a general-purpose, stand-alone, full-constellation, 10-channel, real-time GPS simulator with integrated high-stability timing reference, as well as an internal GNSS receiver for monitoring the RF output signal for quality and accuracy. The unit will transmit a standard UTC time, position, velocity and heading GPS L1 C/A RF signal by simply applying 3.3V power to it.

The Micro-Transcoder can also be operated as a generic GPS simulator with built-in GPS Disciplined Oscillator (GPSDO), and is supported by a free Windows application downloadable from the JLT website. The Windows application allows control of all the simulation aspects, creating and storing simulation vector commands and testing user equipment for leap-second and GPS week rollover event compatibility to identify weaknesses in user equipment. The unit does not require a connected PC to function. The Micro-Transcoder is also available mounted onto an evaluation board for easy evaluation. The unit transcodes baseband PNT NMEA signals into a GPS L1 RF signal with typically less than 100-ms latency. UTC 1PPS timing-transfer accuracy to the GPS RF output is typically better than 5 ns. The unit requires only 3.3V to operate, and setup, location and simulation vector file information can optionally be stored in its internal NV memory.

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Compact, High-Accuracy Navigation Solutions

THE EMCORE IMU ADVANTAGE:

EMCORE's EN-300 is form, fit and function compatible with legacy IMUs, but delivers five- to ten-times the performance. EMCORE's EN-150 is the smallest, most affordable closed-loop FOG IMU available and delivers twice the performance of competing IMUs.

- Three-axis closed-loop FOG design for improved drift stability, higher linearity and greater flexibility
- Designed to operate as an IMU or navigator
- Low-noise line-of-sight stabilization
- Next-generation integrated optics and FPGA electronics
- Vertically-integrated manufacturing in Alhambra, CA

Applications

- Inertial navigation system for missiles, UAVs
- Platform stabilization in gun targeting systems
- Dismounted soldier north finding and navigation
- Operation where GPS is denied or unavailable

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OROLIA

GSG-5/6 SERIES

All Constellations, All Frequencies

For those responsible for mission-critical PNT applications, the Orolia GSG series of GPS/GNSS simulators is an important tool to evaluate risk for jamming, spoofing or any other threat. Orolia GSG-5/6 series simulators are easy to use, feature-rich and affordable, offering a way to harden GPS-based systems without the limitations of testing from "live sky" signals. The Orolia platform approach allows customers to buy only what they need today and upgrade later. The adaptability of the GNSS RF generation platform can extend to applications for intelligent repeating.

Test Solutions

- Position accuracy and dynamic range/sensitivity
- Simulate movements/trajectories anywhere on or above Earth
- Sensitivity to GPS impairments: loss of satellites, multipath, atmospheric conditions, interference, jamming and spoofing
- Conducted or over-the-air RF
- GPS time-transfer accuracy
- Effect of leap-second transition
- Multi-constellation testing
- Modernization signals/frequencies
- Keyless military SAASM, dual-frequency and survey-grade receiver testing
- Application packages for real-time kinematic (RTK), controlled radiation pattern antennas (CRPA)
- Hardware-in-the-loop (HIL) integration
- Test solutions for eCall and ERA-GLONASS

Infrastructure possibilities include zone-based indoor location (intelligent repeating) and pseudolite applications.

GSG-6 Series 64-channel multi-frequency, advanced GNSS simulator is powerful enough for any cutting-edge test program. GPS, GLONASS, Galileo, Beidou, QZSS and NAVIC (IRNSS) signals are available across multiple frequencies. The GSG-6 is designed for military, research and professional applications.

GSG-5 Series 16-channel multi-constellation L1-band GNSS simulator is designed for commercial development/integration programs. It is for developing commercial products with GNSS capability, and will shorten test programs with confidence.

GSG-51 single-channel signal generator is designed for one purpose — fast, simple go/no-go manufacturing test and validation, ensuring the manufacturing line is operating at full capacity with confidence in quality.

www.orolia.com / sales@orolia.com / +1-585-321-5800

QASCOM

QA707 GNSS AND INTERFERENCE SOFTWARE SIMULATOR

Specifically designed for testing GNSS interferences and cyber-attacks. QA707 has been designed to test robustness against emerging cyber-threats beyond jamming and spoofing. It allows the creation of scenarios with signal and code jamming, data-level cyber-attacks, denial of service threats, low-level spoofing channels control, and trajectory-controlled spoofing.

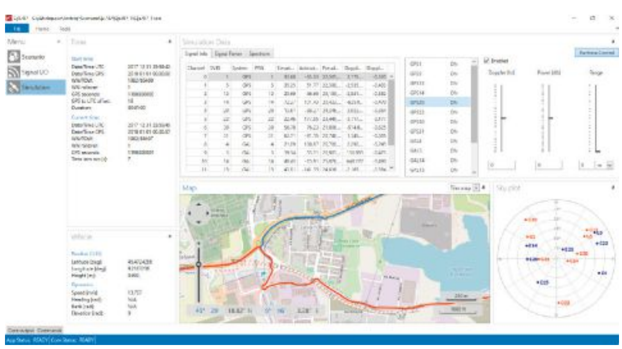
Optimal for signal modernization design. Being a flexible software defined radio (SDR) solution, QA707 is also suitable for testing of signal modernization and for the simulation of new signal components. An open API is provided to create specific signals simulation. Particularly, the tool is ready to support the upcoming Galileo Open Service Authentication (OSNMA).

Runs on a standard PC or laptop with USRP or other hardware. QA707 is compatible with several third-party hardware RF up-converters, including National Instruments' USRP. It also can support customer's specific hardware through the hardware API interface. Qascom introduces the new frontier of GNSS security testing. QA707 is supported from back office with custom services as well as jamming and spoofing mitigation solutions for receivers and applications. This covers 100% of customer GNSS security needs.

QA707 Main Features

- Multi-constellation (GPS L1, Galileo E1, SBAS L1)
- Galileo OSNMA ready
- RF simulation, binary file dump, signal record and replay
- Support to SDR platforms and open API for custom RF upconverters
- Runtime scenario data UDP stream: motion, channel data, simulated inertial sensor
- Data-level cyber attacks
- Low-level spoofing signals control, trajectory spoofing, signal replay attacks
- Narrowband, wideband, frequency modulated jamming
- Integrity threats: evil waveform, erroneous ephemerides, code/carrier divergence, low satellite signal power, excessive range acceleration
- Built-in editing tools: RF output calibration, RINEX editor, trajectory editor

www.qascom.it / info@qascom.it



RACELOGIC

LABSAT 3 WIDEBAND AND SATGEN SOFTWARE

LabSat 3 Wideband

The LabSat 3 Wideband is easy to use, cost-effective and produces extremely low noise, accurate and repeatable signals. Users can record and replay up to three different channels at 56 MHz with a bit depth of up to 3 bits I and 3 bits Q.

The following signals can be recorded and replayed:

- GPS: L1 / L2 / L5
- GLONASS: L1 / L2 / L3
- BeiDou: B1 / B2 / B3
- QZSS: L1 / L2 / L5
- Galileo: E1 / E1a / E5a / E5b / E6
- IRNSS: L5
- SBAS: WAAS, EGNOS, GAGAN, MSAS, SDCM
- L-band GNSS correction services: Terrastar, Veripos, OmniSTAR, StarFire
- 2X CAN, RS232, and digital inputs recorded and replayed tightly synchronized with GNSS data

Small, battery or mains powered and with a removable SSD (up to 4 Tb), LabSat 3 Wideband allows detailed, real-world satellite data to be recorded then replayed on the bench. The rugged enclosure measures a compact 167 x 128 x 46 millimeters and weighs 1.2 kilograms, meaning it can be placed in a backpack and used to reliably record real-world signals in almost any situation.

SatGen Signal Simulation Software

If a user wants to simulate the signals from scratch, Racelogic's latest SatGen signal simulation software can produce synthesized scenarios containing the full complement of popular GNSS signals: GPS L1, L2C, L5, GLONASS L1, L2, Galileo E1, E5, E6 and BeiDou B1, B2.

SatGen software allows users to quickly create accurate scenarios with their own time, place and trajectory, with any combination of constellation and signal that is currently available or will become available in the near future.

Mark Sampson, LabSat Product Manager
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www.labsat.co.uk

ROHDE & SCHWARZ

R&S SMW200A AND R&S SMBV100B SIMULATORS

Precision-sensitive applications such as autonomous driving, control of unmanned aerial vehicles (UAV), or positioning of aircrafts during landing procedures in coordination with ground-based augmentation systems (GBAS) require that modern GNSSreceivers undergo detailed tests before implementation.

Designed to generate highly realistic test scenarios, Rohde & Schwarz signal generators like the **R&S SMW200A** and the **R&S SMBV100B** offer a unique approach to generating complex and highly realistic scenarios for testing of GNSS receivers that are able to work with diverse navigational systems such as GPS, GLONASS, Galileo, BeiDou and QZSS/SBAS signals. The R&S SMW200A and the R&S SMBV100B can emulate them all for testing.

R&S SMW200A

The R&S SMW200A GNSS simulator (pictured above) can be used to produce complex interference scenarios with multiple interferers — all generated within the instrument itself. It can emulate up to 144 GNSS channels and can be equipped with up to four RF outputs. With its ability to simulate multi-constellation, multi-frequency, multi-antenna and multi-vehicle scenarios, the R&S SMW200A is able to cover a variety of high-end GNSS applications.

R&S SMBV100B

The R&S SMBV100B supports the same navigational systems, with access to 24 GNSS channels and one RF output, with the same ability to configure realistic scenarios including obscuration, multipath and atmospheric effects, as well as the specific characteristics of the antenna and the simulated vehicle. An integrated noise and CW interference generator can also be added.

Since the devices do not require an external PC for scenario configuration, all the tests can be created quickly through the user-friendly GUI. Due to all-encompassing instrument options available, both simulators can be set up to fit unique user requirements.

For testing GNSS receivers under controlled and repeatable conditions, the R&S SMW200A and the R&S SMBV100B provide extensive and cost-effective solutions. The platforms are ready to adapt to future requirements and testing of newly implemented GNSS signals.

www.rohde-schwarz.com
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+49 89 4129 12345

SKYDEL

SDX: SOFTWARE-DEFINED GNSS SIMULATOR

SDX is a proven and advanced GNSS simulator based on GPU-accelerated computing and software-defined radio (SDR).

It is available as a complete turnkey system suitable for all GNSS simulation needs, including everything from compact test benches to complete CRPA test systems, such as SDX wavefront and SDX anechoic. Moreover, its software-defined roots enable the selection of cost-effective hardware into configurations that can be repurposed for different projects.

The architecture behind SDX provides real-time simulation of uncompromising accuracy. It features advanced signal customization and supports configurable outputs. IQ data can be generated in, or imported back into, the simulator as well. The API is embedded in the simulator core, enabling deep automation with a few simple clicks, as well as complex scripts developed with popular programming languages.

SDX simulates multiple constellations on multiple frequencies (GPS, Galileo, GLONASS, BeiDou and SBAS) on a large number of channels. Encrypted codes are supported for GPS and Galileo.

The **Advanced Jammer** module in SDX gives users complete control over interference creation. It is integrated directly into simulation scenarios to enable dynamic jammers (up to 120dB J/S) to interact with GNSS signals.

SDX also allows users to create advanced scenarios suitable for any type of vehicle: antenna patterns (receiver and GNSS SV), LEO/GEO/HEO orbits, multipath, hardware-in-the-loop (HIL), additive pseudorange errors, message modification and corruption, raw logging and more.

It is suitable for the design and validation of GNSS receivers, complex integration, academic research, NAVWAR and test engineering.

SDX is developed and actively supported by Skydel's engineering teams and worldwide distributors. Skydel offers direct support to clients to ensure prompt deployment and integration, or to review advanced customization requirements.

www.skydelsolutions.com
sales@skydelsolutions.com
1-438-239-7924

SPIRENT FEDERAL SYSTEMS

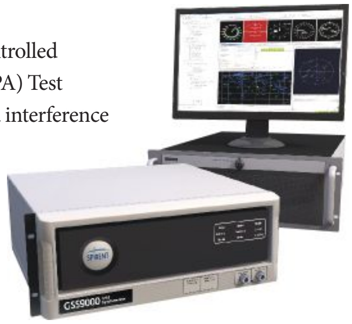
GSS9000, SIMMNSA, CRPA TEST SYSTEM, ANECHOIC CHAMBER TESTING, MID-RANGE TESTING

Spirent Federal provides GPS/GNSS test equipment that covers all applications, including research and development, integration/verification, and production testing.

GSS9000. The Spirent GSS9000 Multi-Frequency, Multi-GNSS RF Constellation Simulator is Spirent's most comprehensive simulation solution. It can simulate signals from all GNSS and regional navigation systems and has a system iteration rate (SIR) of 1000 Hz (1 ms), enabling higher dynamic simulations with more accuracy and fidelity. The GSS9000 supports restricted/classified signals. Users can evaluate the resilience of navigation systems to interference and spoofing attacks, and have the flexibility to reconfigure constellations, channels, and frequencies between test runs or test cases.

SimMNSA. SimMNSA allows authorized users to simulate true M-code for the first time ever. SimMNSA has been successfully delivered to users of the GSS9000 series simulator. SimMNSA has been granted Security Approval by the Global Positioning System Directorate.

CRPA Test System. Spirent's Controlled Reception Pattern Antenna (CRPA) Test System generates both GNSS and interference signals. Users can control multiple antenna elements. Null-steering and space/time adaptive CRPA testing are both supported by this comprehensive approach.



Anechoic Chamber Testing. Spirent's GSS9790 Multi-Output, Multi-GNSS RF Constellation Wave-Front Simulator System is a development of the GSS9000. The GSS9790 is a unique solution providing the core element for GNSS applications that require a test system that can be used in both conducted (lab) and radiated (chamber) conditions.

Mid-Range Solutions. Spirent also offers solutions that cater to intermediate GPS/GNSS testing needs. The GSS7000 multi-constellation simulator provides an easy-to-use solution for GNSS testing that can grow with users' requirements. The GSS6450 RF record & playback system enables replay of a real-world GNSS/GPS test repeatedly in the lab.

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gnssinfo@spirentfederal.com

TALEN-X

BROADSIM

A scalable software-defined simulation platform powered by Skydel's SDX, capable of generating high-fidelity GNSS and jamming signals simultaneously across multiple constellations and vehicles. Simultaneously simulate every signal below:

- GPS Open Codes: L1 C/A, L1C, L1P, L2P, L2C, L5
- GPS Encrypted Codes: L1/L2 P(Y)-Code, L1/L2 AES M-code, L1/L2 MNSA (Coming soon)
- GLONASS: G1, G2
- Galileo: E1, E5a, E5b
- BeiDou: B1, B2
- SBAS: L1, L5
- Jamming

BroadSim's software-defined platform includes intuitive user control and APIs; fast development cycles; flexible licensing and upgradability; and no additional hardware needed to maintain.

Forms

Original (4U)

- Rack-mounted 4U simulator used for lab or field testing
- 4 RF outputs (unlimited jamming signals generated on 1)
- 1000-Hz simulation iteration rate
- High-performance processor, GPUs and memory

Anechoic

- Simulation system used for anechoic chamber testing
- 32 RF outputs and 16 dual-frequency antennas
- Automatic antenna mapping
- Automatic time delay and power loss calibration

Wavefront

- Phase coherent simulation system
- Real-time automated phase calibration
- Scalable from 4 to 16 elements
- Supports CRPA and multi-element receiver testing
- Supports jamming and spoofing

PANACEA

An automated PNT performance and vulnerability test suite that supports up to 32 UUTs (units under test) in real time, from test plan creation to post-test evaluation.

- Time synchronization to live sky
- Compatible with 100+ different GNSS receiver brands
- Create dynamic scenarios with parameters such as jamming patterns, motions, power loss, delays and more.
- Manages receiver communication and standardizes data output for easy analysis, visualization and reporting

www.talen-x.com / sales@talen-x.com

SYSTEM OF SYSTEMS

FIRST LIGHT, *continued from page 14.*

Page	Content
1	GPS/UTC parameters, leap seconds
2	GPS/Galileo and GPS/GLONASS time offset, Earth orientation parameters
3	Reduced almanac
4	Midi almanac
5	Differential corrections
6	ASCII text (29 characters)
7	Reserved

TABLE 1 **Currently defined pages of the CNAV-2 subframe 3.**

ephemeris parameters that allow for a smoother orbit representation compared to LNAV. Multi-GNSS applications benefit from the GPS/GNSS time offset (GGTO) parameters included in page 2. In the same page, Earth orientation parameters are provided that are relevant for users of an inertial frame, such as for spaceborne navigation. The CNAV-2 repeat cycle of 18 seconds allows for a faster access to broadcast ephemerides included in subframe 2 compared to LNAV. Compared to CNAV, CNAV-2 furthermore provides a more sophisticated error detection and correction scheme.

As of the beginning of February 2019, only pages 1, 2 and 4 of CNAV-2 subframe 3 are being used. Within a cycle of 144 seconds, page 1, page 2 and six sets of page 4 midi almanac data (each for one individual satellite) are transmitted. The full almanac for 32 satellites is thus transferred in an average of about 13 minutes. The content in these subframes corresponds to that in L2 and L5 CNAV messages. Updates of CNAV-2 are performed in two-hour intervals starting at 01:30. This is the same update scheme as for CNAV but different from LNAV where the two-hour intervals start at 00:00.

Note that some time will pass before enough GPS III satellites are transmitting so that users can fully enjoy the benefits of the new L1C signal.

MANUFACTURERS

Spectral measurements at the Weilheim 30-meter antenna were made with a **Rohde & Schwarz** FSQ26 vector signal analyzer. Receiver measurements have been collected with a **JAVAD GNSS** TRE-G3TH receiver running an L1C-capable firmware version. 🌐

PETER STEIGENBERGER and **OLIVER MONTENBRUCK** are scientists at the German Space Operations Center of the German Aerospace Center (DLR). **STEFFEN THOELERT** is an electrical engineer at DLR's Institute of Communications and Navigation. **RICHARD B. LANGLEY** is a professor at the University of New Brunswick and editor of the Innovation column for *GPS World* magazine.

OEM

Skydel Updates SDX with Galileo AltBOC

Skydel Solutions has updated its SDX GNSS simulator to version 19.1. The new version adds Galileo AltBOC signal generation, new atmospheric errors, SBAS improvements and SV antenna patterns.

Galileo AltBOC. SDX now supports Galileo AltBOC as a new GNSS signal type. Current SDX users licensed with the Galileo E5 signal will be able to generate 8 Phase Shift Keying (8-PSK) constant envelope AltBOC after upgrading to SDX 19.1. The signal can be generated by selecting both Galileo E5a and E5b in the output–signal selection panel.

Atmospheric Delays and Improvements to SBAS. Version 19.1 adds a new error type to all SDX users: atmospheric delays. These errors can be compensated with SBAS for SDX licensees with the SBAS option installed. The SBAS message now broadcasts ionospheric error corrections.

Three new interfaces help create, manage and use these error values in simulation scenarios.

Atmospheric Errors (Settings : Global). This panel enables users to review and edit the ionospheric delay values for any SBAS Ionospheric Grid Points (IGPs) . The map view can be navigated (pan and zoom) much like the map panel of the simulation. The edit button brings up an IGP editor used to assign the points values or increase their current value by a set amount.

Ionospheric Masks (Settings: SBAS). SDX users with the SBAS option can use this new interface to assign the true/false value for each point of the different SBAS bands, per service provider. It reuses most of the paradigm of the aforementioned atmospheric error pane.

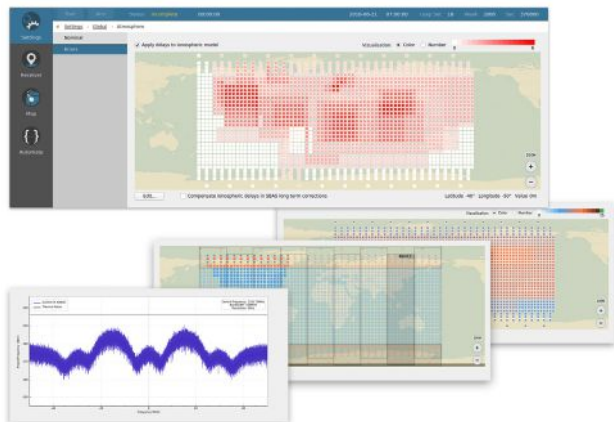

Image: Skydel Solutions

MONTAGE of screenshots showing the various updates in SDK 19.1.

Ionospheric GIVE Indicators (Settings : SBAS). Using a similar map interface as the two previous panels, the GIVEI (GIVE Indicators) panel enables users to provide the GIVE Indicator values for each IGP that is configured in the mask, per service provider.

The grids created or modified with these new options can be saved and imported back into future SDX scenarios.

Talen-X Launches BroadSim Wavefront Simulator, Nano

Talen-X has added the BroadSim Wavefront Simulator to its software-defined platform. The BroadSim Wavefront further extends the capabilities achieved by BroadSim Anechoic, incorporating support for controlled radiation pattern antenna (CRPA) and multi-element receiver testing.

Powered by Skydel SDX, the simulator's features include:

- phase-coherent simulation
- real-time automated phase calibration
- scalability from 4 to 16 elements
- advanced jamming and spoofing scenarios.

Jamming Sensor. Talen-X also introduced the BroadSense Nano GPS jamming sensor, which has the smallest size, weight and power of any BroadSense product.

A video of a Nano prototype, showing the unit reacting to various jamming waveforms in real time, is available on the Talen-X website (**www.talen-x.com/broadsense**).

BroadSim Wavefront Simulator at work.

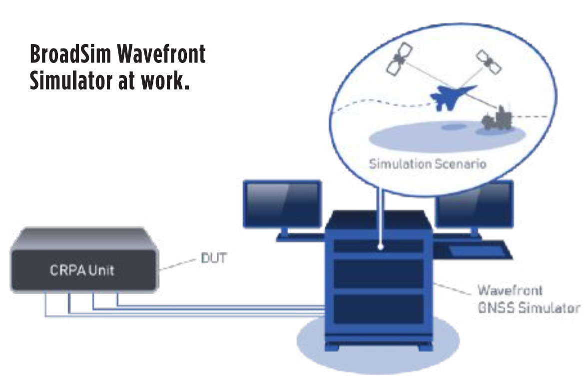

Image: Talen-X

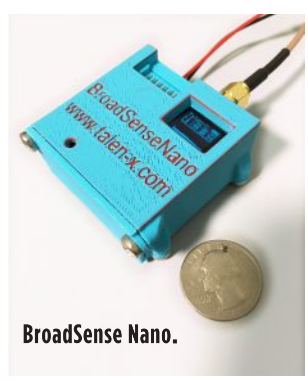

Photo: Talen-X

BroadSense Nano.

TRANSPORTATION

RTK-Inertial Ready for Autonomous Vehicles

Inertial Sense has released a new micro-sized inertial navigation system (INS) with precise real-time-kinematic (RTK)-level accuracy. It offers an accuracy of 2–3 centimeters using GPS positioning in combination with inertial sensors (including on-board sensor fusion), and allows for high accuracy in mass-market applications.

By optimizing the manufacturing processes for high-volume applications, the device is as small and lightweight as a dime. Sensor data from MEMs gyros, accelerometers, magnetometers, barometric pressure and u-blox GPS/GNSS are fused to provide optimal position estimation. Data out includes angular rate, linear acceleration, magnetic field, barometric altitude and GPS time.

The miniature module provides orientation, velocity and position. Base-station corrections data can be applied to achieve centimeter-level precision. The sensor will enable the navigation of all types of autonomous vehicles with a high degree of precision. Evaluation kits are available.

Image: Inertial Sense

SURVEY

MAGNET 5.1 Supports HiPer VR Receiver

Topcon Positioning Group has upgraded its MAGNET suite of software. MAGNET5.1 offers new features, modules and support, as well as a reconfiguration of the Office portfolio to make is easier to use.

Updates to MAGNET Field include support for the new HiPer VR GNSS receiver. HiPer VR includes an integrated IMU and eCompass. It can be used for static or kinematic GNSS post-processed surveys, as a network RTK rover with an internal 4G/LTE cellular modem, as a UHF/FH/Longlink jobsite RTK rover, and also in Topcon's patented Hybrid Positioning workflow.

MAGNET 5.1 also includes a piping and trenching module for the oil and gas segment, and the ability to orient and scale a PDF on a field controller and set it as a background image.

The new Office structure — Project, Construction, Site, Survey and Layout — allows customers to select the best software for their project. The five products are consolidated packages of the various MAGNET software services for ease of use and bundling.

Photo: Topcon

Virtual Surveyor Improved for Drone Surveys

Drone surveying and mapping software Virtual Surveyor has added new functionality that enables users to process larger projects without buying more powerful computers or cloud services. This addition is one of several included in version 6.2.

Drones are capturing more data at higher resolution, resulting in enormous files sizes. According to the company, Virtual Surveyor 6.2 solves the problem of large files by offering enhanced clipping and mosaicking functionality.

Users can merge multiple smaller processed pieces of orthophotos and digital surface models into a single project and create smooth edges between these pieces with the new clipping tool. The mosaic can then be exported to a new TIFF file or serve as the basis for a full area virtual survey.

In addition, a 3D Fly Through capability allows users to select spatial bookmarks and waypoints in their scene and create a movie that allows the viewer to fly through the terrain in three dimensions.

Image: Virtual Surveyor

Virtual Surveyor 6.2 also features improved surface handling for volume calculations. This feature was developed primarily for users who measure volumetrics of material piles in drone survey data. The capability makes it easy to represent topographies as triangles, contour lines or outlines without creating three different objects, the company said.

Other enhanced features of version 6.2 include:

- a renumbering tool that allows users to select a set of times, features or geometries in the data set and automatically number them sequentially from any chosen starting number;
- concave hull extraction that allows users to select a section line to create a surface for a curved roadway; and
- boundary selection that allows users to trace around an unwanted feature and delete that object and all the points within it.

UAV

Yuneec's H520 Drone Gets RTK from Fixposition

Yuneec International's commercial hexacopter, the H520, will now optionally be available with an RTK (real-time kinematic) system from Swiss startup Fixposition.

Under difficult GPS conditions, such as in cities or canyons, the RTK system ensures maximum precision and centimeter-level positioning. The fully integrated RTK satellite navigation enables extremely accurate recurring images and faster 3D mapping. It also makes automated inspection flights easier and more precise.

Photo: Yuneec

The new H520 RTK, available in the second quarter of this year, is suitable for commercial applications that require maximum precision. By using RTK technology, the H520 can now fly much closer to objects for inspection as the UAV positions itself precisely in the centimeter range (1 cm + ppm horizontal / 1.5 cm + ppm vertical) rather than in the meter range, which is standard for the H520.

This accuracy is paramount for applications where several images need to be taken at the same location on different days including:

- documenting progress on construction sites,
- inspecting mountain landscapes to prevent natural hazards such as rock falls or avalanches, and
- forensic accident scene reconstruction.

BETTER JAMMING MITIGATION

Using Wavelets for a Robust Vector-Tracking-Based GPS Software Receiver

BY HAIDY Y. ELGHAMRAWY, MOHAMED YOUSSEF AND ABOELMAGD M. NOURELDIN

> "The wavelet packet transform, widely used to mitigate pulsed and narrowband interference, here features significantly reduced computational complexity."

GPS technology has been integrated into many aspects of our daily lives. Hence, there is a growing demand for a robust GPS receiver that can operate efficiently without external aiding to provide continuous, reliable and accurate positioning, navigation and timing (PNT) solutions. However, this is not always possible due to frequent loss or attenuation of signals, multipath or interference. In such challenging conditions, a system malfunction can cause safety problems, especially in health-critical applications.

Receiver architecture plays a major role in defining a receiver's robustness against the challenges just mentioned. Scalar-tracking-based GPS receivers can achieve high navigation accuracy under line-of-sight (LOS) conditions. However, they always fail to provide adequate accuracy in signal-degraded environments such as urban, suburban and dense foliage environments. On the contrary, vector-tracking-based GPS receivers provide better performance in such challenging environments. In vector-tracking-based receivers, both the tracking loops and the navigation processor are combined to solve a single estimation problem. Hence, there are many advantages of this architecture over that of scalar-tracking-based receivers. First, information from strong signals from healthy satellites is used to track weak signals, when signals are highly attenuated or even totally blocked. Thus, vector-tracking-based receivers have better immunity to jamming and interference. Second, they can rapidly reacquire signals after a satellite outage. Third, they have an improved navigation solution accuracy compared to that of scalar-tracking-based receivers, even under normal LOS conditions. All of these advantages make vector-tracking-based receivers the best platform for our research on receiver robustness. However, vector-tracking-based receivers still suffer from degraded performance in the presence of strong jamming signals. Therefore, we are proposing a new anti-jamming technique to be employed for interference mitigation in vector-tracking-based GPS receivers.

The spread-spectrum nature of GPS signals provides resistance to narrowband interference due to the spreading and despreading processes that take place at the transmitter and receiver respectively. However, a GPS signal reaches the receiver with very low power on the order of –158 dBW, which makes it vulnerable to jamming. A jammer with enough power and suitable time and frequency properties can degrade the positioning solution accuracy and may cause a total blockage of the GPS signals. Besides, the presence of a jamming signal increases the challenge of acquisition of the desired GPS signal. Therefore, many anti-jamming techniques have been employed for interference mitigation in GPS receivers. There are various anti-jamming methods for GPS receiving systems, which are mainly classified into four groups:

1. Antenna-level techniques, which are based on the use of antenna arrays to generate a radiation (reception) pattern that attenuates the interference signal based on the direction of arrival.
2. Automatic gain control (AGC), where interference can be detected by the saturation of the AGC.
3. Post-correlation techniques, which process the signals after passing through the correlators.
4. Pre-correlation techniques, which are based on processing the signals after passing through the analog-to-digital converter but before they get to the correlators.

This article introduces a novel interference mitigation technique based on the wavelet packet transform (WPT), which belongs to the pre-correlation techniques category. The WPT enables the received interfered combined GPS signal to be represented in a transformed domain in which an interference signal can be better identified and separated, without significant degradation of the useful GPS signal. The WPT has been extensively discussed in the literature in the framework of GPS and other GNSS. For example, wavelet multi-resolution analysis has been used in one study to remove the multipath error and leave the useful signal untouched. In another study, multi-resolution analysis using wavelets was applied to pseudorange and carrier-phase GPS double differences to reduce multipath effects. And in another, researchers developed a technique to detect and remove cycle slips based on wavelet multiresolution analysis.

The WPT has been widely used in the context of jamming to mitigate pulsed and narrowband interference. Although the WPT showed outstanding performance in jamming mitigation, the main drawback of this technique is the computational complexity. In this article, we introduce a novel wavelet packet-based technique for narrowband jamming mitigation with significantly reduced computational complexity.

SIGNAL AND INTERFERENCE MODELS

The GPS signal employs a direct sequence spread spectrum communication technique, in which the signal is multiplied by a spreading or pseudorandom noise (PRN) code. As mentioned earlier, this spreading technique gives GPS some immunity to narrowband jamming. The received digitized spread spectrum signal at the output of the receiver's analog to digital converter (ADC) can be represented by:

$$s(n) = \sum_{m=1}^{M} y_m(nT_s) + j(nT_s) + w(nT_s) \qquad (1)$$

where, for signal s, $y_m(nT_s)$ is the useful GPS signal received from mth LOS satellite, $j(nT_s)$ is the jamming signal, $w(nT_s)$ is additive white Gaussian noise (AWGN), M is the number of visible satellites, n is the sample number and T_s is the sampling rate.

The useful received GPS signal can be described as follows:

$$y(n) = \sqrt{2P} \cdot d(nT_s - n_o) \cdot c(nT_s - n_o) \cdot \cos\left(2\pi\left(f_{IF} + f_d\right)nT_s + \theta_o\right) \qquad (2)$$

INNOVATION INSIGHTS

BY RICHARD B. LANGLEY

ALFRÉD HAAR. Who is he, you might ask? Alfréd Haar was a Hungarian mathematician who introduced the concept of wavelets during his Ph.D. work on orthogonal functional systems under David Hilbert of Hilbert transform fame. And what is a wavelet? Generally speaking, a wavelet, as its name suggests, is a brief oscillation in time with an amplitude that begins at zero, goes through one or more variations, and returns to zero. It's a bit like the cardiac cycle of each heartbeat shown on an electrocardiogram. But wavelets, unlike heartbeats, are mathematical functions with well-defined properties.

Although Haar initiated the use of wavelets back in 1909, it was not until the 1970s and 1980s that the study of the use of wavelets — wavelet analysis — was undertaken to help solve a variety of problems in science and engineering with new application areas springing up all the time. We'll get to one of these new areas — GNSS jamming mitigation — in just a bit, but let's discuss a more mundane application first.

Let's say we have a digitized audio recording of Maynard Ferguson's rendition of "MacArthur Park" in our computer. We could do a Fourier transform (related to the Hilbert transform mentioned earlier) of the entire recording, which would show us all of the specific audio frequencies making up the song. But what if we wanted to determine where in the song Ferguson played a particular high note, such as double high C (not his highest)? We could create a wavelet with that frequency and a short duration such as that of a 32nd note and use the mathematical operation of convolution (involving shifting, multiplication and integration) to find one or more spots in the recording with a similar frequency. We could extend the procedure and use a set or bank of wavelets to fully study the song in both frequency and time.

Wavelet analysis will work on many kinds of data, not just audio signals. With an appropriate set of wavelets, we could decompose the data without gaps or overlap, store the resulting product for further analyses and, if necessary, reconstitute the original data with minimal distortion. The U.S. Federal Bureau of Investigation uses wavelet analysis to store compressed digital versions of fingerprint images. A heavily damaged recording of Brahms playing one of his own compositions on an Edison wax cylinder was partially restored using wavelet analysis despite the music being immersed in noise. And the small effect of El Niños on the Earth's rotation has been studied using wavelet analysis.

And, yes, wavelet analysis is helping to improve the use of GNSS. The tasks being undertaken include de-noising of pseudorange measurements, cycle-slip detection and elimination in carrier-phase measurements, and separating biases such as multipath from high-frequency receiver noise. In this month's column (which, by the way, now appears four times per year), we learn about another GNSS application of wavelet analysis — specifically the use of the wavelet packet transform — to efficiently identify and separate a jamming signal from the combined signal in a GPS receiver. In a narrowband jamming test using a hardware simulator system, no positioning was possible with conventional receiver operation. But with the proposed approach, the jamming signal was readily suppressed, allowing the satellite signals to be acquired and a positioning solution to be computed. Thank you, Alfréd Haar.

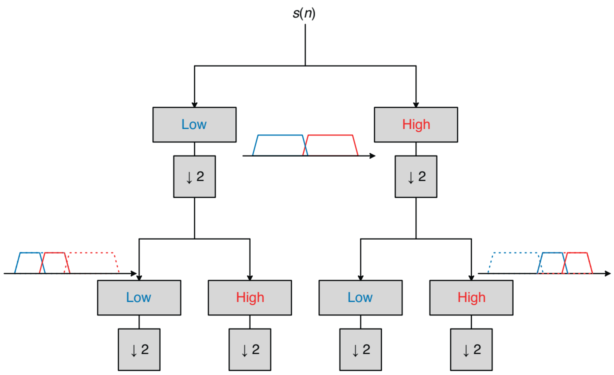

FIGURE 1 Wavelet packet filter banks.

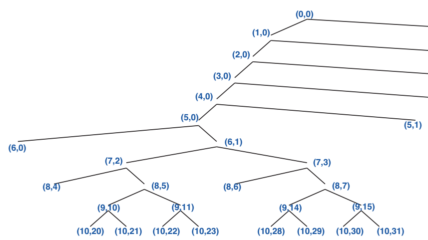

FIGURE 2 Tree decomposition for scenario I.

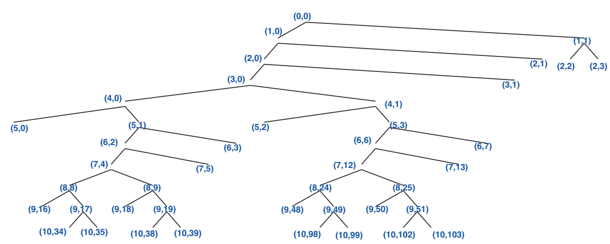

FIGURE 3 Tree decomposition for scenario II.

where P is the signal power, $d(nT_s)$ is the navigation data, $c(nT_s)$ is the spreading pseudorandom noise code, f_{IF} is the intermediate frequency, n_o is the code delay, f_d is the Doppler shift, and θ_o is the carrier phase.

Interference signals are classified based on their spectrum characteristics: narrowband or wideband depending on the signal's bandwidth relative to the bandwidth of the desired GPS signal.

Our focus in this article is on the mitigation of narrowband interference, specifically a linear chirp signal. A chirp signal can be expressed as:

$$j(t) = a\sin\left(2\pi\left(f_o + \frac{k}{2}t\right)t\right) \qquad \forall\ t: 0 \le t \le T_{sw} \tag{3}$$

where a is the chirp signal amplitude, f_o is the starting frequency, k is the sweeping frequency, and T_{sw} is the sweeping frequency period. The chirp is continuously repeated.

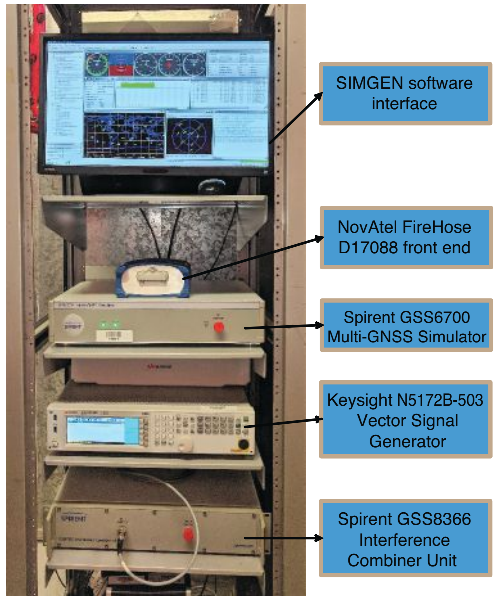

FIGURE 4 Hardware experimental setup.

WAVELET PACKET TRANSFORM

The wavelet packet transform or WPT is a class of transformed domain techniques that has been widely used in the context of jamming mitigation in GPS signal reception. It allows for the study of a signal in both time and frequency domains simultaneously. In the WPT, the signal is decomposed into approximations (the low-pass component) and details (the high-pass component) with respect to a group of local basis functions. These functions can be obtained through dyadic scaling and shifting of the so-called mother wavelet. The discrete wavelet basis functions are given by:

$$\psi_{j,k}(t) = \frac{1}{\sqrt{s_o^j}}\psi\left(\frac{t - k\tau_o s_o^j}{s_o^j}\right) \tag{4}$$

where j and k are integers, s_o is the dilation step, and τ_o is the scaling coefficient. The decomposition of the signal with respect to a scaling function acts as low-pass filtering of the signal, while the decomposition with respect to a wavelet function acts as high-pass filtering of the signal. The signal is then down-sampled, and this procedure is further iterated on all the sub-bands using scaled and dilated versions of the wavelet and scaling functions. This filtering process allows the decomposition of the GPS signal with respect to a local basis function, in which each of these sub-bands identifies a limited frequency band of the received signal, and the frequency resolution is dependent on the level of decomposition. The wavelet packet decomposition can be realized as a filter-bank as depicted in **FIGURE 1**.

JAMMING MITIGATION ALGORITHM

As mentioned earlier, the main drawback of WPT is the time complexity. Due to the decomposition of both approximation and detail components, if the signal is decomposed into L levels, the resultant number of coefficients is $2L$. For instance, if we used 10 decomposition levels, the resultant number of wavelet coefficients is 2^{10} (1,024). However, as each wavelet coefficient component represents a limited portion of the frequency of the received signal, the jamming signal will only affect a few coefficients. Thus, the main idea of the proposed algorithm is to identify those coefficients that are affected by the jamming signal and reconstruct the jamming signal after denoising them. Then, the estimated jamming signal is subtracted from the received signal to obtain the jamming-free useful GPS signal.

Identifying the wavelet coefficients affected by interference is achieved by computing the median absolute deviation (MAD). As those coefficients that are affected by interference have a higher MAD value than those that are not affected, the decision of whether the wavelet coefficients are affected by interference is based on comparing their MAD values with a certain predefined threshold. This threshold is determined based on the desired detection and false alarm probabilities

Parameter	Value	Unit
Simulated signal	GPS L1	
Sampling frequency	20	MHz
Quantization bits	2	bit
Intermediate frequency	0	Hz
Noise floor	-130	dBm
Coherent integration time	2	msec
Non-coherent integration blocks	2	
Wavelet decomposition level	10	
Wavelet	Symlets 8	
Jamming signal type	Linear-chirp	
Jamming to signal ratio (JSR)	35	dB
Offset from center frequency	200	kHz
Jamming signal bandwidth	40	kHz
Sweep rate	100	kHz/s

TABLE 1 Data collection and processing parameters.

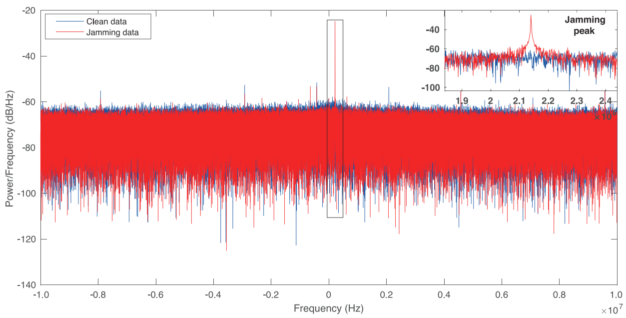

FIGURE 5 **PSD before jamming mitigation.**

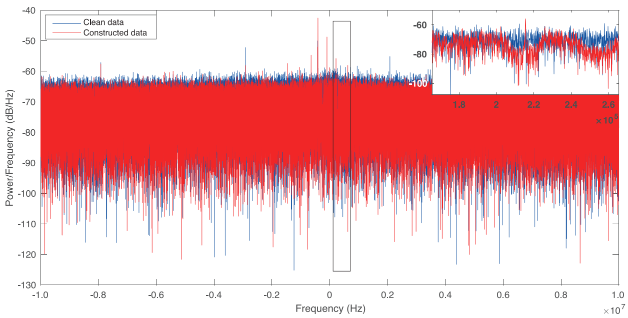

FIGURE 6 **PSD after jamming mitigation.**

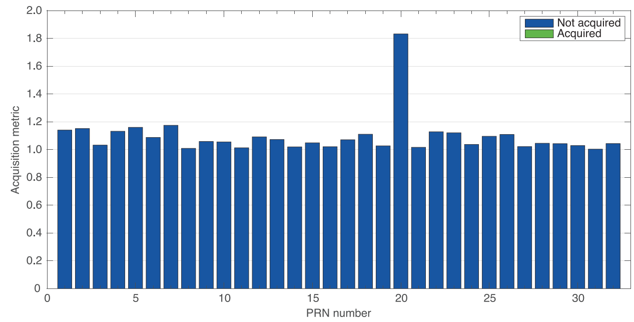

FIGURE 7 **Acquisition results before jamming mitigation.**

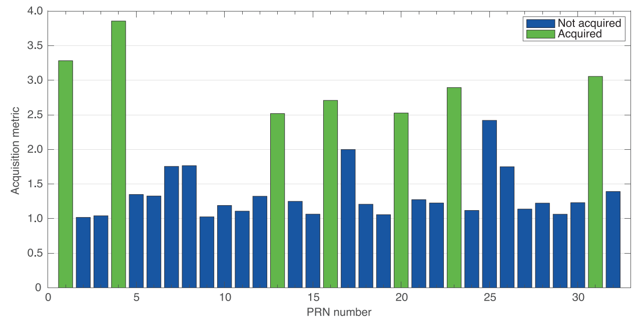

FIGURE 8 **Acquisition results after jamming mitigation.**

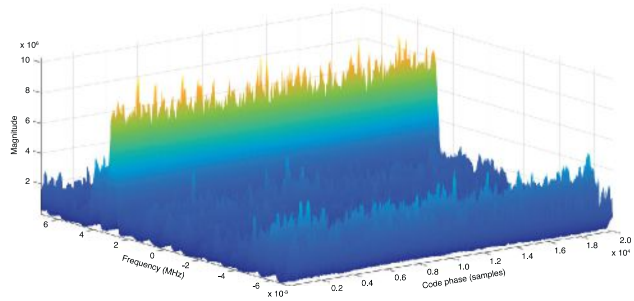

FIGURE 9 **CAF of PRN31 before jamming mitigation.**

according to the distribution of the received signal samples in an interference-free environment. Only the sub-bands whose MAD values exceed the threshold are considered to be affected by interference and are further decomposed.

Therefore, only the sub-bands affected by interference are isolated and iterated. This technique allows for a considerable reduction in complexity, as both detection and mitigation can be applied in a limited number of sub-bands. **FIGURES 2** and **3** show the tree decomposition of the received signal of two jamming scenarios based on the proposed algorithm. The frequency offset of the jamming signal from the GPS signal is 200 kHz in the first scenario and 600 kHz in the second one. The figures clearly illustrate the huge reduction in computational complexity as for 10 levels of decomposition; we ended up having only eight wavelet coefficients instead of 1,024.

The proposed wavelet packet-based detection and mitigation algorithm is explained in three steps.

Decomposition Step. The incoming GPS signal is decomposed through a uniform filter bank by only one level. Then, MAD is computed for all the decomposed sub-bands. Only sub-bands with a MAD value greater than the predefined threshold will be further decomposed. This step is repeated until the maximum predefined decomposition level is reached.

Detection Step. The MAD value is computed for all sub-bands from the last decomposition level. Only sub-bands whose MAD value exceeds the predefined threshold are considered affected by interference and are used to reconstruct the jamming signal using the inverse wavelet transform.

Reconstruction Step. In this step, the useful GPS signal is reconstructed free of interference by subtracting the estimated jamming signal from the received signal.

EXPERIMENTAL WORK

In our investigation, a GNSS simulation system was used to create a fully controlled environment to examine and validate the performance of the proposed method using semi-real simulation scenarios. The simulator was controlled by simulation software that enables the simulation of multipath reflections through an advanced multipath model as well as atmospheric degradation to signals and the effects of antenna patterns and terrain obscuration. Moreover, it can generate simulated land, air, space and sea trajectories. Furthermore, the

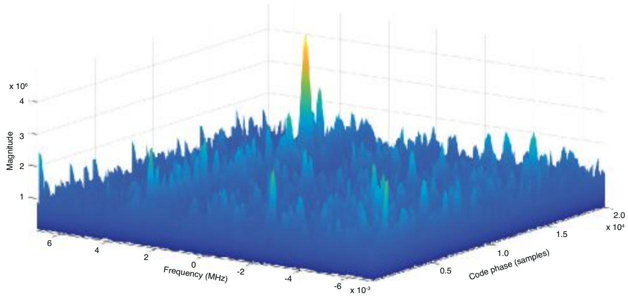

FIGURE 10 **CAF of PRN31 after jamming mitigation.**

simulator when connected to an interference simulation system can provide various controlled jamming environments using an interference signal generator. The full setup is shown in **FIGURE 4**.

The receiver used in this research is a prototype of a digital front end. The front end collects the output radio frequency (RF) signal from the simulator. Then, the RF signal is down-converted to baseband through several down-conversion stages, generating the in-phase (I) and quadrature-phase (Q) data. Then, the data is sampled and quantized through the ADC. The front end collects GPS L1 signals at different bandwidths ranging from 2.5 MHz to 20 MHz with quantization levels ranging from 1-bit to 8-bit. After that, the sampled digitized signal is sent to the computer via an Ethernet connection. The raw I/Q GPS samples are then processed by a GPS software receiver. Our proposed algorithms have been implemented using Matlab by modifying the open-source GPS software-defined radio (SDR) receiver composed by Borre and Akos, which is widely used in research.

To verify the performance of the new proposed algorithm, a full GPS C/A-code signal was simulated using the previously mentioned simulation system. A static simulated scenario was generated for this purpose. This static scenario was run twice, once in an interference-free environment for reference, and one where the jamming signal was enabled. The simulation, front end and SDR receiver parameters are shown in **TABLE 1**.

FIGURES 5 and **6** show the power spectral density (PSD)of the received signal before and after applying the proposed jamming mitigation technique. The figures demonstrate that the interference components have been highly attenuated. To confirm the benefits of the proposed technique, the reconstructed useful GPS signal has been acquired using the SDR receiver. **FIGURE 7** shows that the receiver is in a total blockage as it failed to acquire any satellite before applying the jamming mitigation technique. However, **FIGURE 8** shows that the proposed algorithm allowed the retrieval of seven satellites.

FIGURE 9 shows the cross-ambiguity function (CAF) of PRN31 before jamming mitigation. It is obvious from the figure that the search space is quite noisy, and the receiver fails to acquire the GPS signal due to the difficulty of isolating the peak from the noise. However, **FIGURE 10** shows that the peak clearly emerges from the noise floor and can be easily detected by the receiver after applying the jamming mitigation algorithm.

These figures demonstrate the power of the proposed algorithm and confirms that the useful signal is not lost during the filtering process. Before applying the jamming mitigation algorithm, the receiver lost lock on all satellites and failed to provide a navigation solution. However, after applying the proposed algorithm, the navigation solution is available with an accuracy of about 10 meters in the east and north components and around 20 meters in the up component, as shown in **FIGURE 11**.

CONCLUSION

In this article, we have proposed a new method for mitigating a linear chirp narrowband jamming signal based on the WPT. Although the WPT has been widely used in the literature in the context of mitigating narrowband jamming, this technique is characterized by a significant computational complexity that is not only proportional to the length of the signal, but also proportional to the wavelet decomposition level.

The results show that our proposed algorithm is able to maintain excellent performance in the suppression of the jamming signal with a significant reduction in complexity. In the proposed technique, the sub-bands affected by interference

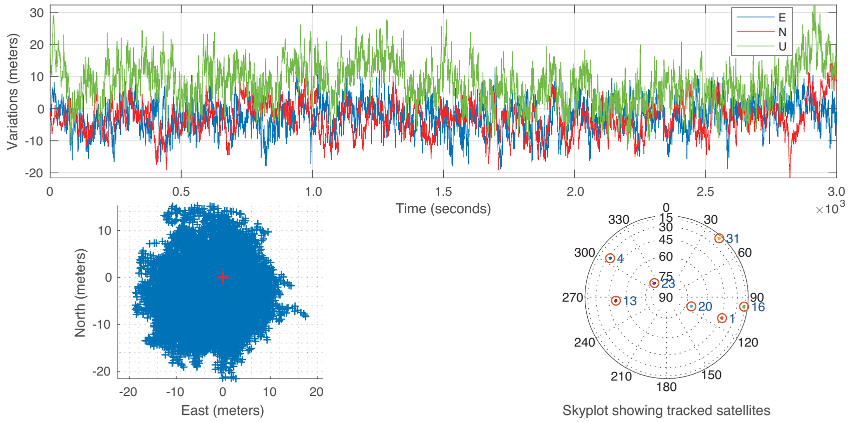

FIGURE 11 Navigation solution.

are identified and are further decomposed to be used to reconstruct the jamming signal. Then, the useful GPS signal is obtained by subtracting the estimated jamming signal from the received signal. The performance of the algorithm has been assessed with respect to acquisition and navigation performance. The results show that the proposed algorithm successfully suppressed narrowband jamming without significantly degrading the useful GPS signal.

ACKNOWLEDGMENTS

This article is based on the paper "A Novel Wavelet Packet-based Jamming Mitigation Technique for Vector Tracking-based GPS Software Receiver" presented at ION GNSS+ 2018, the 31st International Technical Meeting of the Satellite Division of The Institute of Navigation, Miami, Florida, Sept. 24–28, 2018. The research was supported by the Natural Sciences and Engineering Research Council of Canada.

MANUFACTURERS

The simulation system used a Spirent Communications Inc. (*www.spirent.com*) GSS6700 Multi-GNSS Constellation Simulator, a Spirent GSS8366 Interference Combiner Unit and a Keysight Technologies (*www.keysight.com*) N5172B-503 Interference Signal Generator. The receiver front end used was a NovAtel Inc. (*www.novatel.ca*) FireHose D17088 prototype digital GNSS front end.

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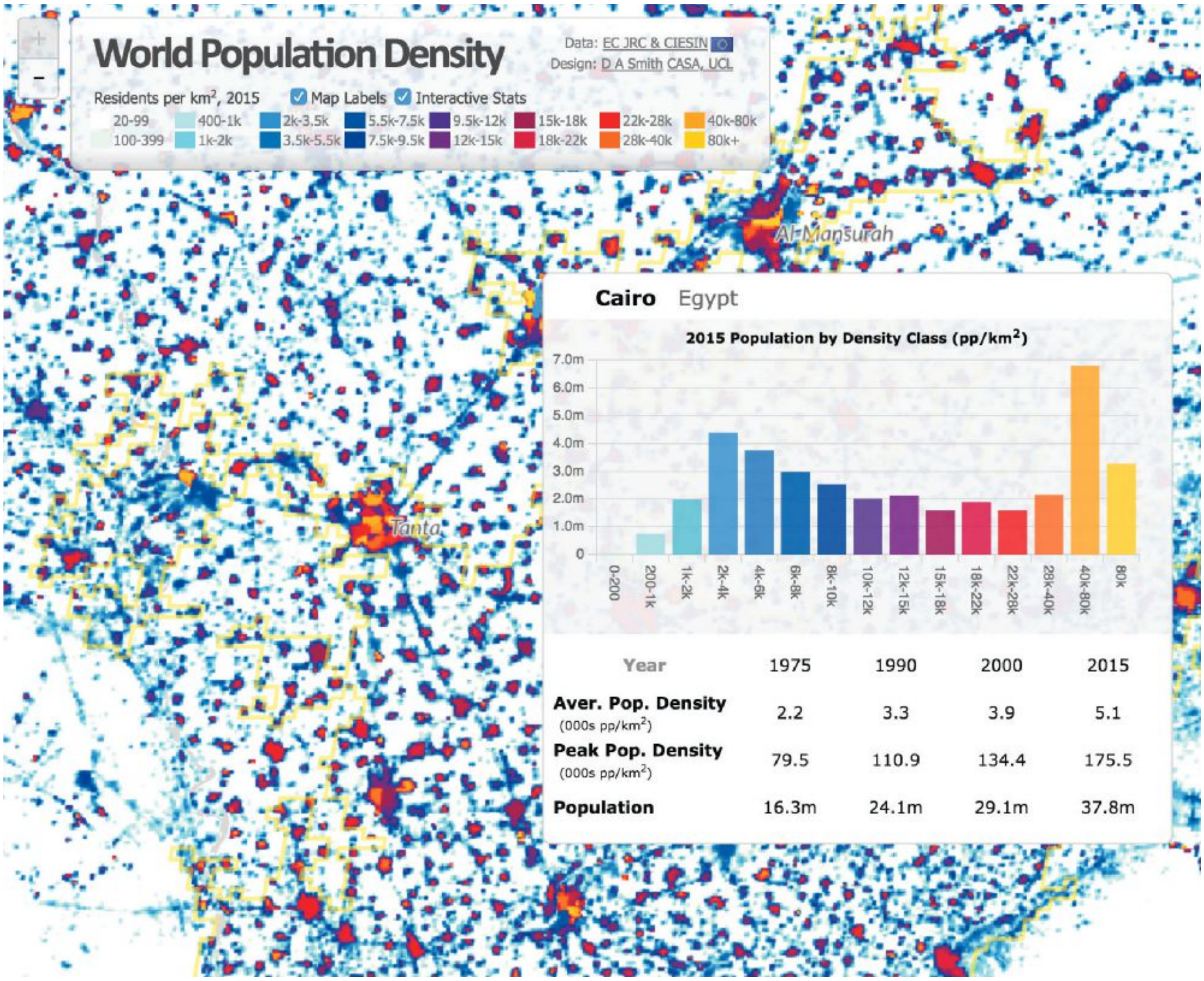


Image: Esri/Joint Research Centre/CARTO

A Geo Window on Africa

Since 1990, the urban population of Africa has doubled, with more than 80% of its denizens living in urban areas. Urbanization can contribute to sustainable growth, if managed well.

However, its speed and scale bring challenges, including meeting accelerated demand for affordable housing, transport systems, infrastructure, basic services and jobs.

Population data such as shown above is only a sample of the geospatial data available in Esri's new Africa GeoPortal (www.africageoportal.com). The Esri-led initiative is a cloud-based platform that provides and receives geographic data and imagery from Esri and its partners.

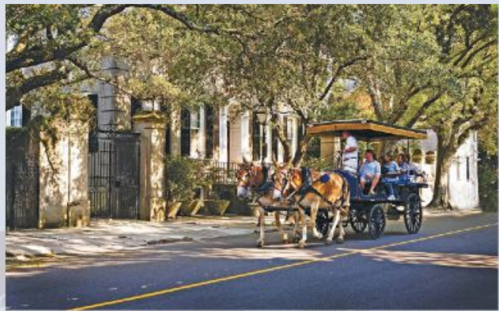
The African Union, African Development Bank, other international agencies, nongovernmental organizations, academia, businesses and national government funds will be able to use the geoportal to address the most urgent development challenges facing the continent — including economic development, climate adaptation, conservation and health care.

The complimentary software-as-a-service geoportal is offered to anyone supporting African nations for positive economic, social and environmental outcomes — African citizens, NGOs and international development agencies. The geoportal offers access to spatial analytics capabilities and authoritative content for charting compelling, educational, informational, entertaining and beautiful maps of Africa.

The Global Human Settlement Layer from the European Commission's Joint Research Centre (JRC) is a complete, consistent, global, free and open dataset on human settlements, and helps to quantify and understand the issues that drive urbanization. The above example comes from the JRC in its Esri story map "Building Knowledge for Sustainable Development in Africa," which shows how the JRC contributes to the African Union (AU)-European Union (EU) partnership.

WHEN HORSES ANSWER THE CALL

Taking a ride in a horse-drawn carriage delights many visitors to historic Charleston, South Carolina. Until now, city crews cleaning up the presents horses leave behind have relied on flag indicators left by carriage operators. Now the city is testing a new method. Carriage operators will send the exact location to equine sanitation crews using small GPS-enabled devices. When a horse or mule takes an on-street nature break, the guide presses a button, and the equine sanitation crew is notified of exactly where to go. When the cleanup is complete, the notification is deleted.



DETECTING RAIN OVER THE OCEAN

Despite a wide variety of monitored geophysical parameters, GNSS signals reflected off the Earth's surface (GNSS reflectometry) have never been used to obtain rain information. A new study presents evidence that data from the U.K.'s TechDemoSat-1 potentially enables the GNSS-R technique to detect precipitation over oceans at low winds. The study — by scientists at the GFZ German Research Center for Geosciences at Potsdam — could serve as a starting point for developing a new GNSS reflectometry application, which might also be implemented for low-cost GNSS remote-sensing missions.

GAMING WITH GALILEO

Gamers around the world can now play with the Galileo constellation. Callisto for Android uses Galileo signals in a virtual maze game based on walking through a real-world location. Looking down on Earth as if from a spaceship, players use a Google Map display to traverse an area filled with randomly generated obstacles and collectibles. The project began as an entry to European Space Agency's Galileo App Competition 2017–2018 and was one of three apps that made it to the finals.

GUINNESS DECISION PENDING ON WORLD'S STEEPEST STREET

Dunedin, New Zealand, claims to have the world's steepest street (Baldwin), a title officially challenged in January by the town of Harlech, Wales, when residents walked up and down the narrow, winding Ffordd Pen Llech carrying a GNSS surveying receiver. A total of 14 data points were recorded on the 330-meter-long road, which had an altitude accuracy of ±5 centimeters. New Zealand surveyor Richard Hemi said the GNSS method used by the Welsh group might not be accurate. Best accuracy is to survey from the center of the road — easy on Baldwin St. but much more difficult on a winding lane. The survey was sent to Guinness World Records, which will issue a decision this spring.

PHOTO CREDITS: Carriage/Charleston Area CVB; Ffordd Pen Llech/screenshot from Sky News; Calisto/Chocolateam; TechDemoSat-1/SSTL.

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