GPS WORLD

GNSS
POSITIONING
NAVIGATION
TIMING

SIMULATOR Buyers Guide

THE INDUSTRY'S MOST TRUSTED TECHNICAL RESOURCE SINCE 1990

THE GNSS REVOLUTION

From Satellite Signals to Reality Capture

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MEASURING MOUNT EVEREST

HOW TO DEFEAT GNSS INTERFERENCE

MARCH/APRIL 2026 | Vol 37 | No 2
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MARCH/APRIL 2026

Courtesy of Trimble

Today, billions of devices depend on GNSS positioning. Smartphones, vehicles, aircraft, agricultural equipment and industrial systems rely on satellite signals to determine location and synchronize time. Within the geospatial industry, GNSS has evolved beyond navigation. It now serves as the spatial framework anchoring a growing ecosystem of sensors and measurement technologies capable of capturing the physical world in extraordinary detail.

fotoVoyager / E+ / Getty Images

ON THE COVER

A technician prepares the Trimble MX60 mobile mapping system, which integrates dual-head LiDAR and a 72 MP spherical camera suite. Utilizing Trimble ProPoint GNSS-inertial technology for centimeter-level trajectories at highway speeds, the multi-sensor platform enables high-density data collection from the safety of the vehicle, removing personnel from active roadways. (Credit: Trimble)

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Communications-PNT Integration Serves as a New Architectural Layer for Resilient Navigation

BY MOHAMED TAMAZIN

Throughout the past several decades, GNSS has become one of the most significant technologies in modern engineering, supporting transportation, communications, finance, emergency response and critical infrastructure. Its precision, global reach and reliability have enabled entire industries to scale in ways that would otherwise have been impossible. Yet as GNSS is used more deeply in autonomy-driven and safety-critical domains, the limitations of relying on a single-layer PNT architecture are becoming increasingly apparent.

Urban canyons degrade satellite geometry and tracking performance; intentional and unintentional interference is now commonplace; spoofing has shifted from a theoretical concern to an operational reality; and indoor environments, which are essential for robotics, logistics, and emergency services, remain largely outside GNSS's physical reach. These challenges are not shortcomings of GNSS itself. They reflect what the system was originally designed to provide: a globally available positioning and timing reference, not the entire resilience burden for every PNT-dependent application.

Read more at **gpsworld.com/opinions.**

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GNSS POSITIONING NAVIGATION TIMING
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Reliable Resources at the Ready

The *GPS World* Buyers Guide is the only comprehensive and continuously updated directory of leading providers of GNSS and other positioning, navigation and timing (PNT) solutions and services.

If you're seeking products and services, you have two resources available at your fingertips: the print Buyers Guide that appears in our May/June issue, and the online version that's accessible 24/7 at **gpsworldbuyersguide.com**.

We're proud *GPS World's* Buyers Guide was the industry's first online buyers guide to feature hundreds of manufacturers, products and services. The print version of our Buyers Guide has been available for more than 25 years.

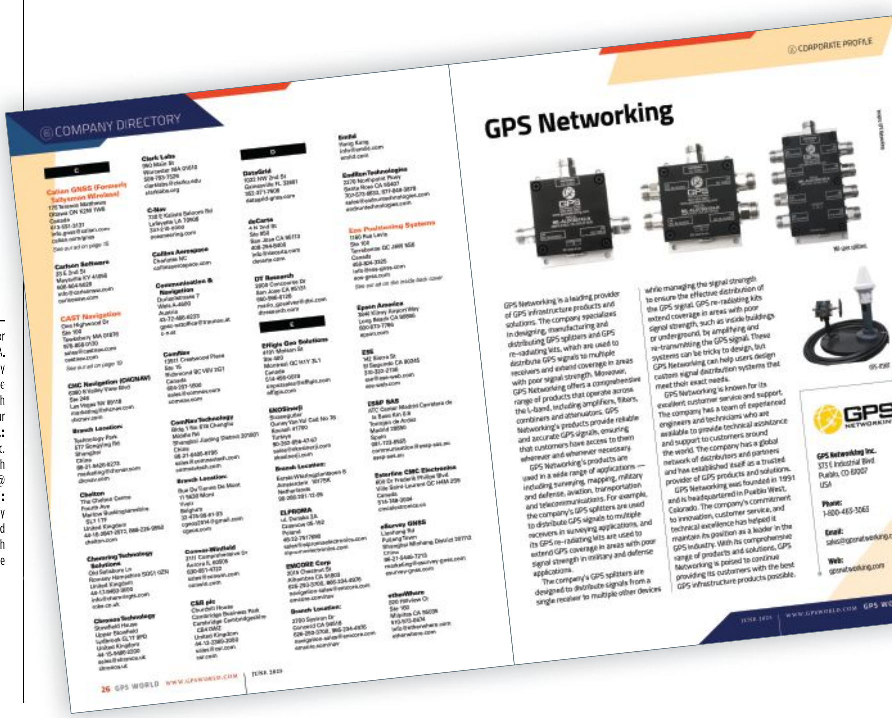
We make it easy to find what you're looking for. You can search for manufacturers by name, or location. You can search for products and services by name, or product categories and subcategories.

We make it easy for manufacturers and suppliers to list their products and services. It's free because we want to ensure our Buyers Guide is all-inclusive and offers accurate and reliable information. We encourage manufacturers and suppliers not listed in our Buyers Guide to create a new listing, which can be continuously updated and seen year-round.

The *GPS World* Buyers Guide is the industry's most trusted resource of GNSS and PNT solutions and service providers. Watch for the latest version in the May/June issue and online at **gpsworldbuyersguide.com**.

In the meantime, check out our Simulator Buyers Guide on page 35 of this issue. It features simulator tools, devices and software from prominent companies that aid GNSS receiver manufacturers in product design.

You can rely on *GPS World* to deliver trusted, reliable resources when you need them most.



Which emerging sectors are driving the most demand for advanced positioning and timing solutions right now?

Miguel Amor
Septentrio

Thibault Bonnevie
SBG Systems

Alison Brown
NAVSYS Corporation

Ismael Colomina
GeoNumerics

Bernard Gruber
Northrop Grumman

Richard B. Langley
University of New Brunswick

Paul McBurney
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Jules McNeff
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Mitch Narins
Strategic Synergies

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Imperial College London

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

Stuart Riley
Trimble

Michael Swiek
GPS Alliance

Julian Thomas
Racelogic Ltd.

Rob Van Brunt
Spirent Federal Systems, Now Part of Keysight

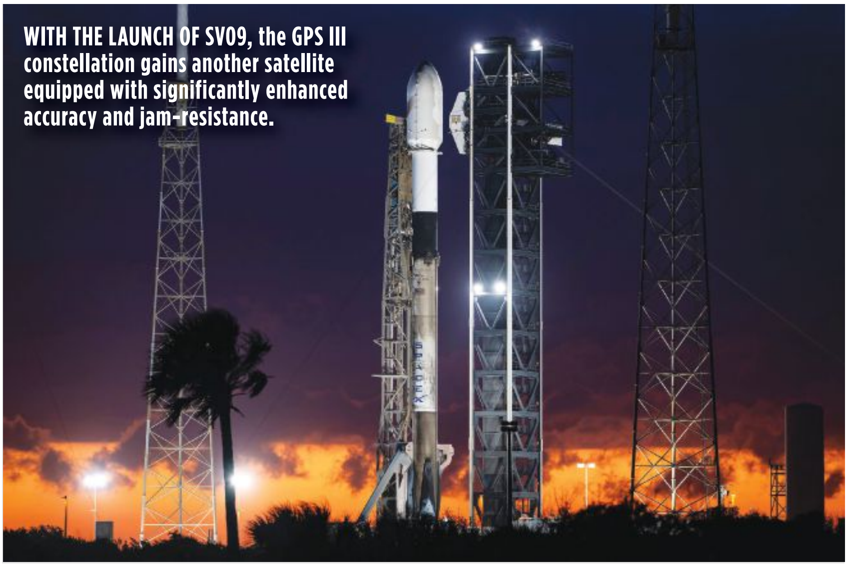
“The primary driver is the broad adoption of autonomy and automation across industries such as construction, logistics, agriculture, infrastructure, defense, or even entertainment. Amplifying this demand is the proliferation of smaller and lighter UAVs, drones and robots. Where a single manned platform once required one navigation system, a drone swarm may require hundreds or thousands of units. It is the combination of these two forces, adopting autonomy and automation and multiplying platforms, that is driving demand growth.”

“The defense sector needs an off-the-shelf GNSS module that is small, light and low power, yet also highly resilient — such as a military-grade location system — to satisfy the insatiable growth in drones. While this segment is about a tenth of the total commercial vehicle market, it is significant compared to the emerging autonomous driving segment, where the need for resilience is still trying to figure out the cost-benefit of mitigating intentional interference.”

“If I had to pick newly emergent sectors with the highest need for precise and continuous PNT, I would say the autonomous system operations sector and portion of the artificial intelligence (AI) sector. AI cannot provide spatially or temporally ‘intelligent’ support if it does not have access to precise positioning and timing information from outside itself. PNT sources do not depend on AI, but ‘autonomous’ AI must have reliable PNT.”

“For many, the meaning of advanced positioning and timing solutions equates to solutions that provide higher accuracy and precision. For me, achieving an advanced PNT solution must require equal focus on the other PNT metrics — availability, integrity, continuity and coverage. Given the tumultuous state of the world these days, there is an emerging demand for solutions that enable resilient PNT in the defense sector, the commercial aviation and maritime sectors, in telecommunications and in power.”

Read the full responses at **gpsworld.com/opinions**



WITH THE LAUNCH OF SV09, the GPS III constellation gains another satellite equipped with significantly enhanced accuracy and jam-resistance.

SpaceX

Ninth GPS III Satellite Joins Constellation

The ninth GPS III satellite was successfully launched into orbit on Jan. 27 from Space Launch Complex (SLC)-40 at Cape Canaveral Space Force Station, Florida, aboard a SpaceX Falcon 9 rocket.

The launch was originally scheduled for Jan. 25, but was delayed due to weather conditions.

SV09 was deployed from the rocket's upper stage about 1.5 hours after liftoff.

GPS III satellites, equipped with M-code technology, provide the warfighter with a significantly more accurate and jam-resistant capability. Adding another such satellite to the constellation enhances the system's robustness and ultimately boosts the warfighting lethality of the Joint Force.

Two field commands were overseeing the mission: the Space Force's Space Systems Command (SSC) and Combat Forces Command (CFC). SSC's System Delta 80 (SYD 80) helps manage the National Security Space Launch (NSSL) program, the procurement process for launch vehicles; and CFC's Mission Delta 31 is responsible for pre-launch satellite processing alongside Lockheed Martin, the satellite's manufacturer.

"For this launch, we traded a GPS III mission from a Vulcan to a Falcon 9, then exchanged a later GPS IIIF mission from a Falcon Heavy to a Vulcan," said USSF Col. Ryan Hiserote, SYD 80 Commander and NSSL program manager. "Our commitment to keeping things flexible — programmatically and contractually — means that we can pivot when necessary to changing circumstances. We have a proven ability to adapt the launch manifest to complex and dynamic factors and are continuing to shorten our timelines for delivering critical capabilities to warfighters."

SV09 is named in honor of Col. Ellison Onizuka, a U.S. Air Force test pilot and NASA astronaut. 🌐

US Space Force Cancels Smallsat Project for Resilient GPS Program

The U.S. Space Force has ended an exploratory effort to add smaller, lower-cost navigation satellites to strengthen the existing GPS constellation.

The Space Force does not plan to move forward with on-orbit demonstrations of industy-designed smallsats under the Resilient GPS (R-GPS) program, which began in 2024. In September of that year, the Space Force selected Astranis, L3Harris Technologies and Sierra Space to develop concepts for small, cost-effective navigation satellites to increase GPS resilience, using an expedited "quick start" contract process.

But funding for the next phase of the program was not included in the fiscal year 2026 budget because of higher U.S. Department of the Air Force priorities.

R-GPS was part of a broader push by the Pentagon to diversify satellite architectures amid concerns that spacecraft are vulnerable to interference or attack.

The Space Force has not said whether it plans to pursue alternative PNT efforts in place of R-GPS. 🌐

EUSPA Contracts for GNSS Demonstrator

EUSPA has signed a framework contract with Thales Alenia Space to build the European GNSS Service Demonstrator (ESD), a centralized modular platform advancing EU Space services like EGNOS, Galileo, Copernicus and GOVSATCOM/IRIS2.

The EGNSS Service Demonstrator is a key innovation accelerator for EUSPA, paving the way for large-scale end-to-end testing of future Galileo and EGNOS augmentation services through both geostationary satellite and internet-based dissemination.

The system will serve as the backbone of pre-operational EGNSS service validation, anticipating future positioning, navigation and timing (PNT) user needs across critical markets, support standardization activities, and sustain EUSPA's commitment to service excellence.

The ESD will comprise modular and flexible ground and support segments to handle a diverse number of reference stations and data. It will be able to compute corrections, messages or data that will be disseminated in real-time via different means such as GEO SiS and the internet.

It centralizes EGNSS demonstrations, incorporating future services like high accuracy (HAS), authentication (OSNMA, SAS), maritime/rail DFMC safety, space weather and emergency warning via scalable infrastructure.

The ESD will facilitate the seamless rollout of new/improved services without disrupting operations of current EGNSS services, emulating signals for realistic testing to support future prototyping and standarization of receivers (such as for rail safety or automotive high-accuracy units) and app development. It will refine user needs across sectors while engaging users and developers.

KEY USE CASES

The main use cases the ESD will cover are:

- Early Open Service signals, such as pre-operational EGNOS DFMC SBAS or Galileo HAS integrity, to accelerate user readiness.
- Service consolidation for evolutions like enhanced HAS via E-GSC interface, OS-NMA/SAS testing, and sector-specific apps (maritime, rail).
- Standardization support for receivers like MUGG, EDG2E and Fundamental Elements projects; SBAS promotions and demos.

BeaconSat Aims to Make GNSS Attacks Visible

Austria is breaking new ground in space. BeaconSat is the largest satellite ever developed in Austria and also the country's first military satellite. The project is being led by Austrian start-up GATE Space, based in Schwechat. Launch is planned for February 2027 aboard a SpaceX Falcon 9 rocket.

BeaconSat is designed to detect and analyze jamming and spoofing attacks on GNSS — targeted attempts to interfere with and manipulate navigation signals such as GPS or Galileo. Austria is responding to a security policy development that has real implications for aviation, transport, energy supply and military operations.

"Space is now a central component of Europe's and Austria's security and defense strategy," said Major General Friedrich Teichmann, head of the ICT and Cybersecurity Center. Navigation signals have long been part of critical infrastructure, and securing them is therefore of great strategic importance.

However, many of these attacks remain invisible. Countries often do not know where the interference is coming from, how systematic it is, or what pattern lies behind it. This is where BeaconSat comes in.

BeaconSat will systematically detect and analyze GNSS interference signals from orbit for the first time. The aim is to obtain data on when and where navigation systems are being deliberately disrupted. The mission is designed as a multi-year research and development project.

The satellite is not intended to be an isolated military project, but rather a demonstrator. Civil space technologies are being further developed for security-related applications and tested under real-world conditions. The findings will be incorporated into the operational processes of the Federal Ministry of Defense (BMVL).

IRNSS Loses a Satellite

One of India's four navigation satellites failed March 10, a setback for the NavIC network. Satellite IRNSS-1F was lost after its atomic clock stopped functioning.

Only three satellites — IRNSS-1B, IRNSS-1L and NVS-01 — remain operational for providing positioning, navigation and timing (PNT) services across the Indian subcontinent. The loss of one degrades location services provided by the NavIC system, a regional navigation satellite system designed to augment global systems (an SBAS).

ISRO

GNSS GLOBAL NAVIGATION SATELLITE SYSTEM **PNT** POSITIONING, NAVIGATION AND TIMING

Q+A with Safran Electronics & Defense

Quentin Ceruti

Testing Trust in GNSS: Why Simulation Matters for Civil-Sector Applications

To start, can you explain why GNSS has become so critical for civil applications today?

GNSS really sits at the heart of many civil applications today. It's no longer just about navigation — it also underpins precise timing, synchronization, automation, and a wide range of safety-critical functions. Industries such as aviation, automotive, smart mobility, telecommunications, energy and agriculture all depend heavily on GNSS — whether it be legacy or low-Earth orbit (LEO) signals. As that dependence increases, ensuring systems continue to perform reliably in all operating conditions has become a key concern for civil sector users.

In this context, what role does GNSS signal simulation play for civil applications?

What simulation brings, first and foremost, is control. It allows engineers to test and validate GNSS-based systems in realistic environments, but without relying on live signals. With simulation, you can reproduce complex or degraded conditions — challenging vehicle dynamics, interference, difficult environments, constellation changes — in a fully repeatable way. This is extremely valuable for development, validation and certification, as it helps teams identify issues early, reduce field testing and ultimately shorten development cycles.

What are the key technological characteristics of modern GNSS simulators?

Modern GNSS simulators can generate highly realistic RF GNSS signals in real time. This means accurately modeling satellite constellations (both medium-Earth orbit (MEO) and LEO), signal structures, navigation messages and timing behavior across multiple constellations and frequencies at once. High iteration rates and low latency are especially important when you want to reflect real-world dynamics or run hardware-in-the-loop tests.

Safran's Skydel-powered simulators, such as the GSG-7, provide users a great deal of flexibility. Scenarios can be easily configured or automated, and a fully documented Application Programming Interface (API) makes it straightforward to integrate simulations into lab, validation, or even production test environments. For civil users, this translates into faster testing, more realistic scenarios, and very consistent results.

What are the concrete benefits of Skydel-based simulators for civil-sector users, and can you share an example from precision agriculture?

In practical terms, Skydel-based simulators, such as the GSG-7 or GSG-8 Gen2, help civil-sector users test GNSS-based systems in a safe, repeatable and cost-effective way. It reduces reliance on field trials and allows performance to be accurately assessed under controlled conditions before deployment.

Precision agriculture is a great example of how a GNSS simulator can vastly improve the accuracy and reliability of applications such as automated guidance, section control and variable-rate operations. In addition, a Skydel simulator — such as the GSG-8 Gen2 with dual antenna capabilities — is ideal for simulating the high-accuracy techniques often used in precision agriculture, such as real-time kinematic (RTK) or precise-point positioning (PPP), including correction streams, convergence behavior, vehicle dynamics and satellite geometry. This makes it possible to evaluate guidance accuracy at the 2 cm to 3 cm level, check pass-to-pass repeatability within a few centimeters, and study PPP convergence times ranging from a few minutes to several tens of minutes, depending on the PA scenario.

The result is greater confidence that equipment will deliver reliable, centimeter-level precision once it's in the field, helping farmers improve efficiency and productivity.

Quentin Ceruti, Product Manager


ELECTRONICS & DEFENSE
OBSERVE, DECIDE, GUIDE
INTELLIGENCE ONBOARD
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LAUNCHPAD | SURVEYING & MAPPING

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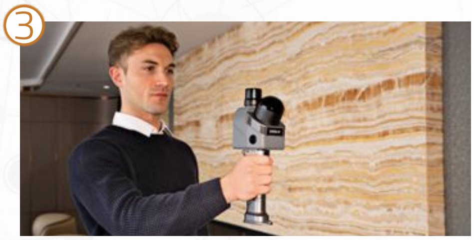


4


1. MAPPING APPLICATION

HIGH-PRECISION GNSS FOR IOS AND ANDROID SMARTPHONES

FastXY can transform standard mobile devices into professional-grade data-collection tools for geospatial information system (GIS) and architecture, engineering and construction (AEC) professionals. FastXY offers professionals the ability to collect point, line and polygon data, and delivers advanced capabilities including 3D basemaps, construction staking, topographic surveying, on-the-fly datum transformations and survey-grade elevations. A built-in Bluetooth data parser allows users to configure the app to collect data from virtually any instrument supporting BLE Bluetooth or RS-232 — including echosounders, radiation sensors, laser rangefinders, barcode scanners and more — and marry that data instantly with precise GNSS coordinates. Available in free and premium versions.
Digital Mapping Group, fastxy.com

2. MOBILE SCANNER

ALL-IN-ONE SYSTEM OFFERS SLAM, LIDAR, RTK AND 360° IMAGERY

The GX1 is an integrated, highly accurate all-in-one mobile scanning system combining simultaneous localization and mapping (SLAM), lidar, real-time kinematic (RTK) georeferencing, cameras and software. It supports a seamless workflow, from capture to deliverable, and can reduce the time required to survey a site by up to 95%. The independently validated global accuracy of 5 mm to 10 mm delivers the precision needed for topographic and road surveying, scan to building information models, construction progress tracking, and more. These capabilities are supported by integrated RTK georeferencing with real-time quality monitoring, four 20MP cameras for 360° panoramic imagery, and a proven SLAM algorithm. The GX1 has four deployment modes — backpack, survey pole, vehicle mount and supported handheld.
Emesent, emesent.com

3. HANDHELD SCANNER

DESIGNED FOR BIM, INDOOR SURVEYING AND REALITY CAPTURE

The RS7 handheld SLAM (simultaneous localization and mapping) scanning solution was built for BIM documentation, indoor surveying, renovation planning and complex spatial analysis. It is designed to help professionals capture high-density 3D data efficiently and convert it into practical deliverables through CHCNAV's software and cloud ecosystem. The RS7 integrates a next-generation lidar scanner capable of measuring up to 1.15 million points per second. Its wide field of view (360° x 189°) supports comprehensive coverage of floors, walls and ceilings, helping reduce the need for repeated passes and complex capture maneuvers in tight or cluttered spaces. The scanner also includes a high-precision inertial measurement unit with bias stability better than 0.5°/h. By combining lidar and inertial data, the system is designed to maintain stable motion estimation and consistent point-cloud quality in environments that challenge many mobile workflows, including long corridors, repetitive structures, and feature limited interiors.
CHC Navigation, chcnav.com

4. QUAD-BAND GNSS ROVER

WITH SUPPORT FOR GALILEO HIGH ACCURACY SERVICE

The SparkPNT TX2 quad-band GNSS rover combines an IP67-rated aluminum enclosure with support for Galileo's High Accuracy Service (HAS) and standard RTK correction workflows. The receiver is built around the Quectel LG290P quad-band GNSS engine and supports multi-constellation tracking. Galileo HAS support provides sub-20 cm accuracy globally without subscription-based correction services, while RTK workflows via NTRIP or u-blox PointPerfect can achieve centimeter-level positioning. Battery life is rated at 50-plus hours, positioning the TX2 for multi-day field campaigns without recharging. The unit connects to iOS and Android devices via Bluetooth and Wi-Fi, with compatibility reported for common GIS and data-collection applications. A notable design choice is the open-source firmware, which gives users visibility into how positioning data is processed and allows for customization and third-party integration. SparkFun has positioned this as an alternative to closed GNSS ecosystems where firmware and processing pipelines are not user-accessible.
SparkFun Electronics, sparkfun.com 🌐

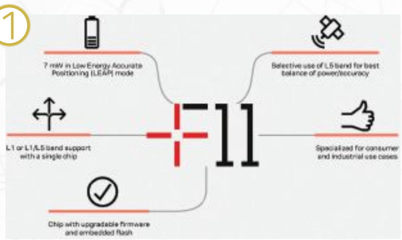
LAUNCHPAD | MOBILE

1. GNSS PLATFORM

PROVIDES ULTRA-LOW POWER GNSS FOR ALL ENVIRONMENTS

The u-blox F11 platform provides L1/L5 dual-band standard-precision GNSS to improve positioning accuracy while reducing power consumption to as low as 7 mW in typical configurations. It combines ultra-low power operation with intelligent signal management to meet the evolving demands of tracking, wearables, telematics and mobility applications — including micromobility solutions and drones. The platform enables device manufacturers to achieve longer battery life, faster and more reliable position fixes, and greater design flexibility. Its situationally aware GNSS architecture, with integrated geofencing and indoor detections, dynamically balance accuracy and power consumption. By selectively using dual-band L1/L5 operation only when it helps maintain positioning performance, the platform reduces energy use while providing resilience and maintaining confidence in location data.

1



u-blox, ublox.com

2. IOT PLATFORM

COMBINES GNSS, SBD AND LTE-M

2

The Iridium 9604 is a compact, three-in-one internet of things (IoT) module that integrates Iridium short burst data satellite service, LTE-M cellular connectivity, and GNSS positioning into a single platform. The Iridium 9604 seeks to make dual-mode IoT connectivity viable for price-sensitive, high-volume deployments. Built on the u-blox SARA-R5 platform, the module comes in a compact 16 mm x 26 mm x 2.4 mm form factor, suitable for dual-mode IoT deployments across industrial, infrastructure and mobility applications.

Iridium Communications, www.iridium.com

3. L1+L5 GNSS MODULES

FOR TRACKERS AND HIGH-PRECISION IOT

Two dual-band positioning modules built on Airoha's AG3335 chipset series are available: the ultracompact SE873K5-D and the high-end SE869eK5-DRK. Both support space- and power-constrained IOT devices and use cases that require continuous, ultraprecise positioning. The modules provide a scalable path to adopt dual-band L1 + L5 GNSS.

3

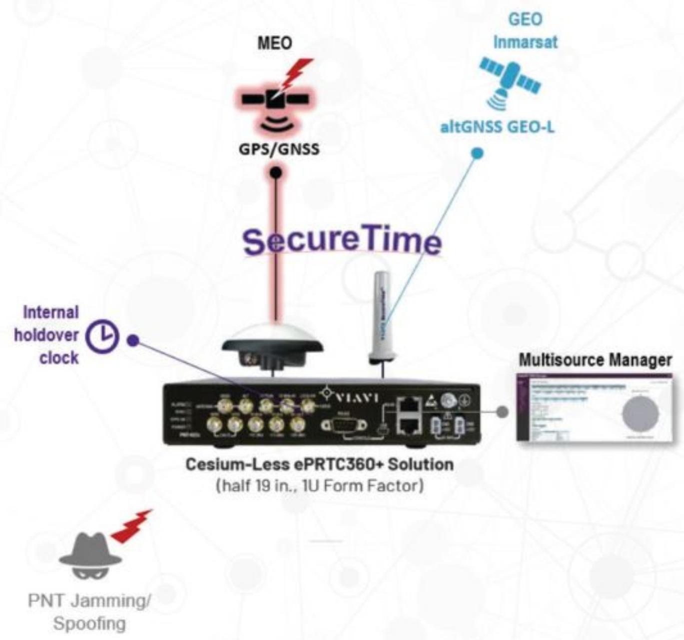
Telit Cinterion, telit.com

CESIUM-LESS CLOCK

AN ALTERNATIVE TO CESIUM-ACCURACY HOLDOVER CLOCKS

The patent-pending Cesium-less ePRTC360+ holdover solution is designed to safeguard at-risk infrastructure against the increased threat of GNSS timing disruptions. It is the only alternative to Cesium clocks to meet ITU-T G.8272.1 standards. It can protect critical power grids; transportation, aviation and public safety systems; 5G mobile networks; and AI data centers. It meets the international ITU-T G.8272.1 standard and has been successfully tested across a range of live-sky defense and commercial jamming/spoofing environments. It has been integrated into VIAVI's SecurePNT 6200 product series and can maintain 100 ns accuracy during GNSS-denied threats through the resilient altGNSS GEO-L service with no time limit.

Viavi Solutions, viavisolutions.com



1. MEMS IMU MODULE

FOR VEHICLES, SHIPS AND DRONES

The U4930 series is a reliable and cost-effective six-axis micro-electromechanical system (MEMS) and inertial measurement unit (IMU) module for navigation, control and measurement of vehicles, ships and drones. Applications include vehicle/ship attitude measurement, UAV attitude reference and trajectory control, mobile mapping, track inspection and underwater high-precision navigation. The U4930 series integrates high-performance MEMS gyroscopes and accelerometers within an independent structure. The three-axis MEMS gyroscopes sense the angular motion of the carrier, and the three-axis MEMS accelerometers sense the linear acceleration of the carrier. The system internally performs compensation for zero bias, scale factor, non-orthogonal error and acceleration-related terms across all temperature parameters, maintaining high measurement accuracy over a long period of time. The module supports custom communication protocols and provides synchronization for GPS/GNSS time data and pulse per second (PPS) signals.

Micro-Magic, memsmag.com

2. UNDERGROUND NAVIGATION

FOR NAVIGATING MINES AND UNMAPPED ENVIRONMENTS

Chimera Land is a 3D laser velocity sensor (LVS) designed to solve the primary challenge for underground mining: maintaining precise vehicle positioning in deep, dark and unmapped environments where GPS cannot reach. When fused with an Advanced Navigation inertial navigation system (INS), Chimera Land allows underground vehicles to maintain stable navigation over extended distances and time. Instead of needing to query an external beacon or satellite for its location, the sensor uses specialized lasers to measure a vehicle's ground-relative 3D velocity with high accuracy. By feeding this precise data into the vehicle's INS, the sensor eliminates the drift that typically comes with standalone INS. Using AdNav Intelligence, the result is a resilient, high-performance, infrastructure-light positioning solution that excels in the high-dust, zero-light conditions typical of underground mines.

Advanced Navigation, advancednavigation.com

GNSS TEST TOOL

PROVIDES REAL-WORLD TESTING WITH SIGNALS FROM THE FIELD

The SimXTRACT GNSS test tool bridges the gap between field and laboratory. It enables signals captured in field environments to be comprehensively decomposed into individual, discrete signals and applied to lab simulation for realism at every stage of the development test cycle. Developers usually rely on either RF record-and-playback or lab simulation for testing and validation of PNT systems and devices. SimXTRACT takes real signals captured in field environments and performs complex signal decomposition, breaking down each received signal into discrete line-of-sight and multipath ray paths, along with metadata such as Doppler offset, code error, power level and angle of arrival. This decomposed environment is then automatically converted into fully controllable simulation scenarios for Spirent GNSS simulators.

Spirent Communications, spirent.com

LAUNCHPAD | AUTONOMOUS

1. INERTIAL MEASUREMENT UNIT

FOR UNMANNED AIR, LAND AND SEA

Honeywell launched the HGuide i700, an inertial measurement unit (IMU) that delivers high-accuracy performance for unmanned air, land and sea vehicles. By pairing near navigation-grade capability with a no-license-required (NLR) classification, the HGuide i700 provides integrators worldwide with a new option for critical sensing and navigation. The HGuide i700 uses high reliability sensors and electronic architecture found in Honeywell's HG3900 inertial measurement unit (IMU). Compact and low power, the HGuide i700 delivers near-navigation-grade accuracy and reliability while being optimized to support longer range navigation in GNSS-denied environments. The HGuide i700 offers strong GNSS-denied performance for by limiting maximum acceleration and spin rates in a license-free package. The latest in Honeywell's HGuide suite of no-license inertial solutions, the HGuide i700 allows customers to streamline development cycles, simplify system architecture and transition to field deployment quickly. The HGuide i700's rugged design, compact size and low-power profile make it suitable for diverse commercial, industrial and defense applications, including autonomous vehicles, mapping and surveying.

Honeywell Aerospace, aerospace.honeywell.com

2. ANTI-JAM ANTENNA SYSTEM

PROVIDES MULTI-CONSTELLATION, MULTI-FREQUENCY G NSS SIGNAL PROTECTION

The GAJT-AE3 protects all major GNSS constellations from jamming with full multi-constellation, multi-frequency coverage, ensuring reliable PNT in demanding airborne environments. Its antenna electronics mitigate interference by creating up to seven nulls per band in the direction of jammers, providing significant anti-jam protection even in dynamic multi-jammer scenarios. The output is a protected radio frequency signal, free from jamming and suitable for input to modern and legacy GNSS receivers. The GAJT-AE3 protects and supports all GNSS frequencies, including L-band corrections and Iridium PNT.

Hexagon | NovAtel, novatel.com

LAUNCHPAD | OEM

1. GNSS BOARD

ALL-BAND, MULTI-FREQUENCY RECEPTION AND HAS-READY

Syslogic's new all-band GNSS expansion board for rugged embedded computers is powered by the u-blox X20 receiver. It supports all major GNSS constellations and frequencies, including L1, L2, L5, L6 and L-band, and enables the use of the Galileo High Accuracy Service (HAS). It provides centimeter-level positioning, opening up new applications across industries such as autonomous field management, operation of construction machinery in remote areas, or navigation of automated guided vehicles and autonomous mobile robots. The GNSS board is designed for worldwide use. The integrated u-blox receiver supports modern correction techniques such as RTK, PPP-RTK and PPP. For the first time, it has been fully optimized for PointPerfect Global, u-blox's proprietary high-precision GNSS correction service, delivering centimeter-level positioning anywhere in the world. This is particularly useful in remote areas without cellular coverage.

Syslogic, syslogic.com

2. GNSS L1/L5 BREAKOUT

FOR METER-LEVEL POSITIONING IN EMBEDDED APPLICATIONS

The SparkFun GNSS L1/L5 Breakout – NEO-F10N (SMA) is a compact GNSS module designed for meter-level positioning accuracy in embedded applications. It uses dual-frequency L1 and L5 bands, with the L5 signal offering improved performance in urban environments due to reduced RF interference within the protected ARNS spectrum.

The board supports concurrent reception of GPS, Galileo and BeiDou, and uses u-blox dual-band multipath mitigation to enhance accuracy in challenging conditions. It features a single UART interface, with an onboard CH340 USB-to-serial converter for easy connection to a computer, and standard pin headers for integration with external systems.

The module includes an SMA connector for secure antenna attachment and is configurable using u-blox u-center software.

SparkFun Electronics, sparkfun.com

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SpatiX is a global Spatial Intelligence company, which was founded in August 2015, and with Alibaba as largest shareholder. The current valuation is about USD 2.2 billion. We have delivered high-precision positioning services to more than 2.6 billion devices globally.SpatiX is the essential Infrastructure for Physical AI, providing the centimeter-level spatial awareness that autonomous agents need to operate safely and reliably at global scale. The autonomous agents include intelligent-driving autos, bikes, cellphones, drones, robots, agricultural systems, geospatial RTK and SLAM devices, etc.

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Scanner

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Lightweight Unmanned
Survey Vessel

Positioning Module and Boxes

A32s

GNSS High-Precision
Dual-Antenna Module

A40s

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How to Defeat Harmful Interference

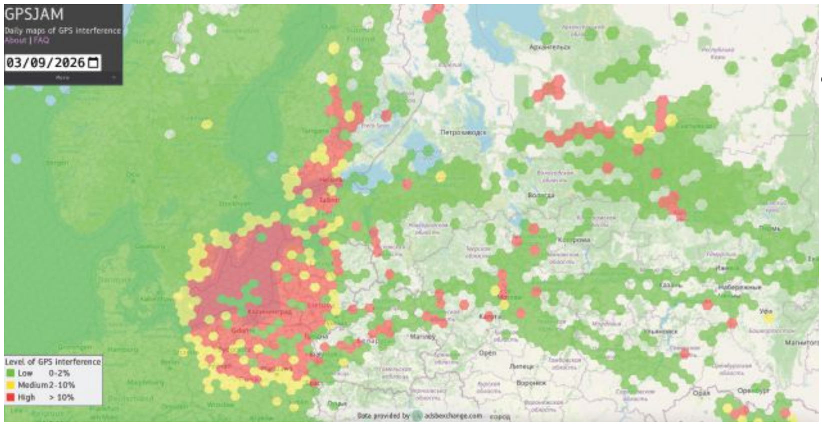
A Roadmap for Action

BY LISA DYER
EXECUTIVE DIRECTOR, GPS INNOVATION ALLIANCE

As *GPS World* readers know, the growing prevalence of GPS/GNSS jamming and spoofing outside of conflict zones interrupts vital aviation safety technologies and presents challenges to maritime commerce and the global economy. An alarming example is playing out along the Baltic Sea and the North Sea, prompting 13 coastal European nations and Iceland to highlight in January 2026 "growing GNSS interference" and collectively reinforce requirements to comply with existing regulations and international law designed to ensure the safety of all maritime vessels engaged in shipping.

As commercial aircraft report navigation anomalies and maritime operators experience false position data in congested waterways, global authorities are sounding alarms that GNSS interference will continue to rise without immediate action. In March 2025, the International Civil Aviation Organization (ICAO), International Telecommunication Union (ITU), and International Maritime Organization (IMO) issued a joint warning expressing "grave concern" that disruptions from GNSS jamming and spoofing constitute an urgent threat to public safety, telecommunications networks, and international commerce.

Compounding harmful interference incidents led the GPS Innovation Alliance (GPSIA) to act. Defeating illegal and harmful interference outside of combat zones requires a coordinated, whole-of-government strategy that focuses on stopping bad actors through deterrence and enforcement, and directing resources toward preventing and sanctioning those violating international commitments and laws prohibiting jamming and spoofing. Investing in GPS modernization and integrating innovative signals from complementary PNT satellite systems into devices and receivers will deliver PNT that surpasses today's technologies to the global community.



DAILY INTERFERENCE MAP from GPSJam.org on March 9, 2026, showing widespread GPS jamming and spoofing across Eastern Europe. High-interference zones (red) are concentrated around Kaliningrad and extend across Poland and the Baltic region, disrupting navigation signals.

Roadmap for Action

In September 2025, GPSIA led a coalition of leading industry groups in sending a letter to the Departments of Defense and Transportation that called for urgent action to address GPS jamming and spoofing. We noted the United States has the technology and expertise to solve this issue, and the administration has the power to act. GPSIA followed the letter with a whole-of-government strategy providing a clear roadmap for the administration. While some recommendations have been implemented, other opportunities remain.

Focus on the Real Culprits

The culprits in each of these scenarios are bad actors putting public safety and global commerce at risk with harmful interference outside conflict zones. The global community relies on several unique technologies that can be impacted by harmful interference, such as cellular and Wi-Fi signals, radars and automated information systems. The misplaced focus on faint GNSS signals or dependencies on GNSS derail collective efforts to immediately regain interference-free global commerce and bolster public safety.

Governments and international organizations mandate certain industries integrate safety-of-life technologies into their operations — and they do, at great cost. Officials should in turn be given the political support and resources to stop bad actors from intentionally interfering with them.

Lockheed Martin

The GPS III satellite has additional anti-interference features.

What to Do Next

Public and continued diplomatic engagement are critical. By amplifying European counterparts, condemnations from senior U.S. officials can raise the reputational costs for bad actors and reaffirm international norms that protect GNSS signals and other technologies from harmful interference.

Engaging with the ICAO is important. The U.S. should reinforce its commitment to providing modern civil GPS signals that support navigation in international airspace and encourage ICAO to prioritize the enforcement of global GNSS protections.

GPSIA also recommends Executive agencies establish an interagency task force that rapidly identifies and disseminates information about interference events with civil operators, including sanitized intelligence information on intentional jamming and spoofing of commercial aircraft and ships.

Civil operators also should be invited to participate in interference coordination calls and reporting. Sharing radio-frequency interference data, incident reports and threat assessments among military and civil agencies and operators is essential to preserving public safety. The Performance-based Operations Aviation Rulemaking Committee's recommendations for continuity of operations during GPS disruption events should continue to be implemented with urgency.

Deterrence and information sharing must be coupled with sustained enforcement. Federal agencies have taken welcome action to interdict illegal jamming equipment, reporting an 830% increase in seizures since 2021. We applaud the U.S. government for prioritizing resources to stop the illegal import and sale of these devices.

GPSIA commends the Kingdom of Norway's annual Jammertest, which allows receiver and device manufacturers to test interference detection and counter jamming and spoofing. These realistic test scenarios, together with strengthened enforcement and prioritized intelligence collection and analysis, will enhance public safety.

Modernize GPS

While GPS satellites continue operating with an extraordinary 99.99% availability and no outages on record, the health of the constellation and jamming and spoofing incidents affecting receivers and devices, demand action. The final GPS III satellite is scheduled to launch this spring. Next-generation GPS IIIF satellites are being built. Their launches should be prioritized to reduce the number of satellites on orbit that are one system or subsystem away from failure. GPSIA welcomed the passage of the FY2026 Defense Appropriations Bill, which bolstered national and economic security by investing needed funding for modernized GPS IIIF satellites and long-term PNT leadership.

Notably, the current GPS program plan does not include counter spoofing technologies. Implementing counter spoofing authentication capabilities for Wide Area Augmentation System (WAAS) signals would further strengthen aviation resilience.

Ground infrastructure modernization is equally important. The GPS ground station must be able to command and monitor GPS III and IIIF satellites and the modern L5 aviation signal.

Streamline Regulatory Activities

Regulatory modernization represents another area of progress. In September 2025, the State Department removed jam-and spoof-resistant Controlled Reception Pattern Antennas (CRPAs) from the International Traffic in Arms Regulations (ITAR), fulfilling one recommendation from GPSIA's strategy.

Certification processes also must evolve, and integration of CRPAs into aircraft should be accelerated. The modern L5 signal and counter spoofing signal authentication signals must be incorporated into FAA-certified and other receivers as soon as possible.

Recommendations for the FCC

President Trump's December 2025 Executive Order (EO), "*Ensuring American Space Superiority,*" directs

U.S. departments and agencies to detect and counter threats to U.S. space infrastructure. It also states that his administration will enable industry to develop and deploy advanced space capabilities, including terrestrial and cislunar PNT applications. This EO should serve as a "North Star" for the FCC, resulting in increased enforcement resources to address illegal jamming and spoofing, and a regulatory environment prioritizing innovative, advanced commercial satellite PNT systems that complement GPS. Demonstrating American leadership in space demands that we step forward, not backwards, in our PNT capabilities.

The FCC is evaluating the record developed in its Notice of Inquiry, *Promoting the Development of PNT Technologies and Solutions,* and is reportedly considering future rulemaking. The FCC's task is not to replace GPS, but to ensure that the regulatory environment protects its spectrum, increases enforcement actions against those perpetuating harmful interference and enables innovation that complements this foundational system. This balanced approach will fulfill President Trump's mandate, preserving public safety and economic security, and ensure continued American leadership in PNT.

> "Sharing radio-frequency interference data, incident reports and threat assessments among military and civil agencies and operators is essential to preserving public safety."

Dmitri Toms / iStock / Getty Images Plus / Getty Images

Baltic and North Sea shipping lanes have become a flashpoint for GPS jamming and spoofing, prompting 13 European nations and Iceland to issue a joint warning in January 2026 over interference threatening maritime safety and global commerce.

Global Safety and Commerce

The FCC's Notice of Inquiry uncovered dozens of PNT technologies, ranging from those in the marketing stage, to hyper-localized solutions, to proposals to exploit "signals of opportunity." Creativity and ingenuity abound in the commission's record, but the docket's many filings lacked technical details to evaluate whether the systems advance the nation's PNT leadership.

The hallmarks of GPS are its worldwide coverage, and the continuity, availability, integrity and accuracy of its signals. Our modern global community deserves complementary PNT systems and signals that meet or exceed GPS capabilities. A few satellite-based solutions stood out as holding promise to do so.

Systems operating in low-Earth orbit (LEO) can transmit stronger signal power due to their proximity to Earth, improving performance in urban environments and contested spectrum conditions. Systems operating in different frequency bands, such as TrustPoint's C-band system, add spectral diversity, making it far more difficult for an adversary to disrupt all PNT services simultaneously. When combined with modernized GPS signals and authentication capabilities, this layered approach can deliver robust services while complementing the foundational role of GPS.

Terrestrial systems cannot replicate global coverage of satellite constellations. They are also vulnerable to wildfires, hurricanes and other disasters. Building parallel terrestrial networks would require significant investment while delivering a fraction of modernized satellite systems' capabilities. Nor do terrestrial signals provide the continuity, availability, integrity and accuracy of satellite systems.

The Progress is Real

GPSIA is pleased to report that progress is being made in several areas outlined in its "whole-of-government" strategy. It's time to accelerate that progress. In May 2026, GPSIA members will convene to evaluate this strategy and outline what more the PNT industry can do to play a part in defeating harmful interference. Our members also will meet with government officials to underpin that government-led enforcement and solutions to jamming and spoofing can further illustrate the importance of PNT to U.S. leadership in space, and national security, public safety and the global economy. 🌐

LISA DYER is executive director of the GPS Innovation Alliance.

Photos courtesy of author

TILT COMPENSATION ALLOWS AN INCREASED SAFETY FACTOR, ALLOWING PRECISON LOCATIONS WHILE STAYING AWAY FROM THE LEDGE. SNAKE RIVER CANYON, IDAHO.

THE GNSS REVOLUTION

FROM SATELLITE SIGNALS TO REALITY CAPTURE

BY JESSE HUFF

During a recent infrastructure survey, a handheld scanning system captured a multi-acre property in less than 15 minutes. As the operator moved through the site, the device continuously scanned the environment while maintaining centimeter-level positioning using satellite signals, inertial sensors and lidar.

The result was a fully georeferenced three-dimensional dataset containing terrain, buildings, trees and infrastructure — captured in a fraction of the time required by traditional survey workflows.

Technologies such as these illustrate how far positioning systems have evolved. What once required multiple instruments, control networks and extended field observation can now be accomplished through integrated sensing systems combining satellite navigation with reality capture.

Yet, the foundation of these capabilities traces back more than six decades.

Today, billions of devices depend on GNSS positioning. Smartphones, vehicles, aircraft, agricultural equipment and industrial systems rely on satellite signals to determine location and synchronize time.

Within the geospatial industry, GNSS has evolved beyond navigation. It now serves as the spatial framework anchoring a growing ecosystem of sensors and measurement technologies capable of capturing the physical world in extraordinary detail.

> "The most important shift, however, is not in the satellites themselves, but in GNSS's role within the broader measurement ecosystem."

Receiver Evolution and Productivity

While satellite constellations and positioning algorithms have steadily improved, many of the most noticeable changes for surveyors have occurred in the instruments themselves.

Modern GNSS receivers are smaller and more efficient than earlier generations. Advances in electronics, antenna design, signal processing and battery technology have reduced size and power requirements while improving reliability and usability in the field.

According to Chris Pappas, owner of Green Forest Surveys and a geospatial thought leader, recent GNSS receiver development has focused on usability rather than increases in raw positioning accuracy.

"What I've seen lately is smaller receivers, longer battery life and smaller antenna sizes on the heads," Pappas said. "The quality has basically remained the same."

These improvements may appear incremental, but they have meaningful impacts on field operations.

Survey crews work in demanding environments such as steep terrain, construction sites, transportation corridors and remote infrastructure locations where equipment weight and power management affect productivity.

"It's portability. It's fatigue from walking up a hill," Pappas explained. "And the longer battery life means you don't have to constantly swap batteries or carry extras. You can take a single set with you and it'll last all day."

Modern receivers also have benefited from advancements in satellite signals and correction services. Today's survey-grade receivers routinely track multiple frequencies from multiple constellations.

Miniaturization is not simply a reduction in size. Achieving multi-constellation tracking, multi-frequency processing and real-time correction required major advances in RF engineering and integrated circuit design.

Capabilities that once required large, power-intensive hardware platforms are now integrated into compact receivers capable of operating an entire day on a single charge.

Signal Modernization, Algorithms and the RTK Engine

While receiver hardware has become smaller and more power-efficient, some of the most significant advancements in GNSS performance have occurred in the algorithms and processing engines operating inside those devices.

Modern receivers are specialized computing platforms designed to process signals from multiple constellations, frequencies and correction sources simultaneously. Tracking multiple constellations enables receivers to observe dozens of satellites while reducing ionospheric and multipath errors.

The real breakthrough, however, has come from improvements in the RTK engine itself.

RTK positioning relies on resolving carrier-phase ambiguities — the unknown integer number of wavelengths between the satellite and the receiver. Earlier RTK systems often required extended initialization periods.

Modern receivers use more sophisticated ambiguity-resolution algorithms that leverage multi-frequency observations and improved statistical modeling. Initialization times have dropped, and solutions are more robust in difficult environments.

Modern RTK engines incorporate advanced filtering techniques, stochastic modeling and automated outlier detection to maintain stable solutions when individual observations become unreliable.

These improvements are particularly important as surveyors increasingly work in environments where GNSS conditions are less than ideal. Urban infrastructure, tree canopy and industrial facilities can obstruct satellite signals and introduce multipath errors.

Advanced filtering architectures allow receivers to reject corrupted observations while maintaining stable positioning using valid measurements.

Many modern receivers incorporate Kalman filtering frameworks that continuously estimate position, velocity, clock bias and measurement uncertainties.

These filters allow GNSS measurements to be integrated with inertial sensors and motion constraints, creating more stable positioning solutions.

Network-based correction services also have become increasingly common. Rather than relying solely on a nearby base station, many surveyors now use network RTK systems that aggregate observations from multiple reference stations across a region.

These networks model atmospheric errors and deliver corrections through cellular or internet connections.

Precise point positioning (PPP) techniques, which use precise orbit and clock information rather than local base stations, also have matured significantly. Modern PPP engines can now resolve centimeter level positioning in real time or near real time, something that only a few years ago could take up to an hour using satellite based augmentation.

These advances have been enabled by the evolution of GNSS chipsets. Modern receivers integrate RF front ends, signal processors and navigation engines into compact system-on-chip architectures capable of tracking dozens of signals while running complex positioning algorithms in real time.

The result is a positioning engine that is no longer confined to a single receiver mounted on a survey pole, but operates as the central reference system for a network of sensors capturing complex environments.

The Maturity of the Modern Positioning Engine

One of the less visible but most important developments in GNSS over the past decade is the maturation of the positioning engine itself.

Early GNSS receivers were essentially signal trackers paired with simple navigation algorithms. Today's receivers function more like specialized computing platforms optimized for real time estimation.

At the core of these systems is an estimation framework that continuously evaluates the quality of each observation entering the solution.

Carrier phase measurements provide the highest precision available from GNSS, but are highly sensitive to noise, multipath and signal interruptions.

Modern RTK engines must balance precision with reliability. Rather than assuming every observation is equally valid, processing engines assign dynamic weights based on signal strength, satellite geometry, atmospheric models and measurement stability.

These approaches allow receivers to maintain accurate positioning even when portions of the satellite environment become unreliable.

The introduction of multi frequency signals also has changed how ambiguity resolution is performed. Earlier RTK systems relied on dual frequency measurements to estimate ionospheric delay and resolve integer ambiguities.

SOLAR STORMS, such as this one in North Carolina, produce beautiful auroras. They also cause signal disruption and interference for GNSS systems. Many of the modern RTK engines now have the ability to filter out this interference and maintain a fix.

With additional frequencies across multiple constellations, modern receivers apply more advanced ambiguity resolution strategies that improve convergence speed.

In practical terms, this means surveyors spend less time waiting for initialization and more time collecting data.

Modern receivers also incorporate tightly integrated filtering architectures. Extended Kalman filtering frameworks continuously estimate position, velocity, clock bias, atmospheric parameters and measurement noise.

These models treat positioning as a dynamic estimation problem rather than a static calculation performed at each epoch.

The result is a positioning engine capable of maintaining stable centimeter level solutions even when signal conditions fluctuate.

For surveyors working in environments with partial satellite obstruction, intermittent multipath or complex site conditions, these improvements often determine whether a day in the field is productive or not.

GNSS as Foundational Infrastructure

Today, GNSS occupies a unique position in the technology landscape. It is both a mature infrastructure system and a platform for continued innovation. The fundamental architecture of satellite navigation has remained largely consistent for decades, while the ecosystem built around those signals has expanded dramatically.

In many ways, GNSS has become invisible because it works so well. Surveyors, engineers and geospatial professionals interact with receivers, correction services and data products rather than with the satellites themselves. Positioning is expected to function, much like electricity or cellular connectivity.

But under that routine operation lies one of the most sophisticated global infrastructure systems ever constructed.

At the space segment level, multiple international constellations provide overlapping coverage. The United States' GPS, Russia's GLONASS, Europe's Galileo and China's BeiDou systems transmit modernized signals designed to improve accuracy, reliability and interoperability. Regional systems such as Japan's QZSS and India's NavIC further strengthen coverage.

This multi-constellation environment represents one of the most significant changes in the GNSS landscape throughout the past two decades. Early survey grade receivers relied primarily on GPS signals, while modern receivers track four or more global constellations simultaneously.

The impact extends beyond redundancy. Observing more satellites improves geometric strength and allows receivers to maintain robust solutions in environments where single constellation systems would struggle, including urban corridors, forested areas and complex infrastructure sites.

Signal modernization has expanded the range of measurements available to positioning engines. Additional civilian frequencies such as GPS L5 and Galileo E5 allow better modeling of ionospheric effects and reduced measurement noise, contributing to more stable positioning solutions.

The most important shift, however, is not in the satellites themselves, but in GNSS's role within the broader measurement ecosystem.

In the surveying and geospatial industries, GNSS has evolved from a standalone measurement technique into the spatial reference framework for modern data capture technologies. It now anchors measurement platforms capable of capturing millions of spatial observations.

In traditional surveying, GNSS remains a primary method for establishing control networks and geodetic reference points, with RTK and post processed kinematic techniques routinely achieving centimeter level accuracy.

In construction and machine control, GNSS enables automated positioning systems that guide heavy equipment using digital terrain models in real time.

In agriculture, precision farming systems use satellite positioning to guide equipment along exact paths, reducing fuel consumption and optimizing inputs.

GNSS also functions as the primary time synchronization system for critical infrastructure, including telecommunications, financial systems and power grids.

For geospatial professionals, the most significant change is how GNSS interacts with emerging measurement technologies. Rather than acting as a standalone sensor, it now operates as the global reference frame for integrated systems.

The satellite-derived position establishes a coordinate foundation that other sensors use to build dense spatial models. In a typical workflow, GNSS establishes the reference, inertial sensors track motion, lidar captures geometry and cameras record imagery.

All observations rely on the GNSS reference frame to maintain spatial consistency.

This enables a shift from discrete point measurement to continuous data capture. Instead of collecting individual points, modern platforms capture millions of observations that can be analyzed and extracted as needed.

GNSS remains the backbone of this process. Even as new sensors emerge, the requirement for a stable global reference frame has not changed. GNSS provides that anchor.

Sensor Fusion and the Expanding Positioning Stack

While GNSS technology continues to evolve, some of the most significant advances in positioning are occurring through integration with other sensing technologies.

Modern positioning systems operate as part of a broader sensor ecosystem. Satellite observations provide the global reference frame, while inertial measurement units track motion and orientation, lidar sensors capture geometry and visual sensors analyze environmental features.

TREES, such as this 150 year old tulip poplar, were killers of previous generation GNSS systems. Robust designs, the modern sensor stack, and powerful algorithms can now fix reliably in heavy canopy, saving hours of traditional work.

Hybrid platforms extend GNSS capability into environments where satellite signals alone may struggle.

Several manufacturers now offer handheld systems that combine GNSS receivers with lidar scanning and inertial navigation. Systems such as the CHC Navigation VLi100 integrate GNSS, lidar, inertial sensing and visual positioning into a single instrument. The VLi100 also incorporates the SureFix 2.0 engine, which uses lidar to stabilize the GNSS position for up to 60 ft after signal loss, extending positioning capability in obstructed environments.

The Tersus S1 SLAM system similarly combines lidar-based mapping with GNSS positioning to capture dense spatial data in complex environments.

The same principles drive mobile mapping systems designed for infrastructure scale data capture. Trimble's MX series, including the MX9 and MX90, combines GNSS positioning, high accuracy inertial navigation and high density lidar to capture detailed spatial data while in motion.

"Sensor fusion is probably the biggest one right now," said Justin Brooks, sales manager for reality capture at Trimble. "When you combine GNSS with lidar and inertial sensors, you're not just collecting points anymore. You're capturing entire environments."

Mobile mapping is increasingly used across the energy sector. According to Jason Rosbach, director, energy solutions at Trimble, large renewable energy projects such as utility scale solar and wind developments require rapid spatial documentation across thousands of acres.

These systems allow survey teams to capture dense geospatial datasets while maintaining consistent positioning through tightly integrated GNSS and inertial navigation.

Carl Bradshaw, director, product management, reality capture at Trimble, explained that GNSS remains the core reference.

"In the MX systems, that GNSS position is the initial core point," Bradshaw said. "Then the IMU interpolates the vehicle path between those GNSS fixes and provides heading, pitch and roll orientation. Every lidar pulse gets geolocated using that combined solution."

Reality Capture and the GNSS Positioning Pyramid

The convergence of GNSS positioning with lidar scanning, inertial navigation, and SLAM-based mapping is driving the broader adoption of reality capture workflows across the geospatial and infrastructure industries.

At the core of these systems remains a GNSS-centric positioning pyramid.

Satellite observations provide the spatial reference that anchors all other measurements.

The additional sensors extend and stabilize that position when conditions become challenging.

From Point Measurement to Spatial Data Acquisition

The integration of GNSS with modern sensing technologies has changed the scale of spatial data collection.

For most of the 20th century, surveying workflows were based on discrete point measurements. Whether using optical instruments, total stations or early GNSS receivers, surveyors collected individual observations that were later combined to construct maps and models.

This approach remains essential for control networks and boundary surveys, but many modern applications now operate at a fundamentally different level of data density.

Lidar scanners, mobile mapping systems and handheld SLAM platforms can collect millions of measurements in minutes. Instead of selecting points, operators move through an environment while continuously capturing geometric observations.

These datasets provide a far more detailed representation of the physical world.

GNSS enables this transition by providing a stable global reference frame. Without it, large point clouds and reality capture datasets would exist only as isolated local models. GNSS allows these datasets to align with engineering design files, geographic information system (GIS) databases and previous survey measurements.

This spatial consistency makes reality capture practical for large infrastructure projects. Transportation departments can compare roadway conditions over time, utilities can integrate asset models and construction teams can verify progress against design.

In each of these workflows, GNSS provides the coordinate framework that keeps datasets aligned across time, sensors and project stages.

The shift from point measurement to continuous data acquisition is one of the most significant changes in geospatial practice in decades.

Even within these systems, positioning still begins with satellite signals. GNSS remains the foundation. Lidar captures geometry, inertial sensors measure motion and SLAM algorithms track environmental features, all fused with the GNSS position.

These systems collect dense spatial observations continuously, allowing entire corridors, facilities and infrastructure sites to be captured rapidly.

Because these datasets are anchored to GNSS positioning, they maintain consistent spatial reference over time.

Looking Ahead

Another development drawing increasing attention across the positioning industry is the emergence of low-Earth orbit (LEO) satellite constellations as potential complements to traditional GNSS systems.

Unlike GNSS satellites operating at medium-Earth orbit altitudes of roughly 20,000 kilometers, LEO satellites orbit much closer to Earth. This proximity allows their signals to reach receivers with significantly higher signal strength and faster acquisition times.

Because the satellites move rapidly across the sky, they also provide constantly changing geometry that can improve positioning performance in environments where traditional GNSS signals struggle.

A number of research groups and commercial companies are now exploring how LEO constellations might augment existing GNSS infrastructure. Some approaches rely on signals from existing communications constellations, while others involve dedicated navigation payloads designed specifically for positioning.

For surveyors and geospatial professionals, the potential benefit is improved positioning reliability in environments where GNSS signals are degraded. Urban corridors, industrial sites and areas with heavy canopy often limit satellite visibility and introduce multipath interference that complicates carrier-phase measurements.

Additional signals from LEO satellites could provide stronger observations in these environments while also improving the redundancy of positioning solutions.

The integration of LEO signals would not replace GNSS but rather expand the broader positioning ecosystem that already has begun to emerge through sensor fusion.

Modern positioning systems increasingly combine GNSS, inertial navigation, lidar, camera and SLAM-based mapping into tightly integrated sensor stacks. GNSS provides the global reference frame, while the other sensors extend and stabilize the positioning solution when satellite visibility becomes limited.

If LEO navigation signals become widely available, they will likely become another layer within that stack.

The long-term result could be positioning systems capable of maintaining centimeter-level trajectories across environments that would have been extremely difficult for GNSS-only solutions just a decade ago.

For the geospatial industry, this evolution represents a continuation of a trend that began decades ago: positioning systems becoming more robust, more integrated, and increasingly capable of capturing the physical world in unprecedented detail.

Author

JESSE HUFF is a geospatial professional with nearly three decades of experience in surveying, GNSS technology and positioning systems. He has worked across field operations, technical development, and industry roles with companies including Trimble, JAVAD GNSS and Tersus GNSS. Huff owns True North Commercial, a geospatial consulting firm focused on GNSS technology, sensor fusion and positioning applications across the surveying, engineering and infrastructure industries.

PEAK XV
From Theodolites to Satellites

The Great Trigonometric Survey: The Framework that Measured Mount Everest

BY WILLIAM H. TEWELOW

A ceiling fan slowly churned, stirring the hot, humid air. Outside, warm rains pelted the muddy streets as distant langurs whooped in the thick jungle mists below.

An incessant fly caught the attention of the office's lone occupant, hunched over a table covered with a large grid-lined sheet of paper. Pencils, erasers, French curves and straightedges lay scattered next to a stack of calculation sheets, but the man holding a pencil in one hand gripped a rolled newspaper in the other, intent on his battle with the fly.

Suddenly, the door burst open.

"Mr. Waugh!" the intruder exclaimed, panting as he rushed in.

"Radhanath," Waugh replied in surprise, looking up from his maps. "I thought you were in Calcutta, 1,600 km away."

"Yes, Mr. Waugh, I was, but this is too important to deliver by post."

"Really, Radhanath. You intrigue me," replied Waugh. "Come out with it. Your excitement is adding to this already unbearable heat."

"Sir," Radhanath tried to say calmly. "I have discovered the highest mountain in the world!"

"Have you now, Radhanath?" Waugh's voice curled to the thought of it. "You found the Mother of the Earth, have you?"

"We have, sir. Peak XV is Chomolungma."

"How did you measure it without getting into Tibet or Nepal?"

That conversation happened in 1852. It was the crown jewel of an effort that began 50 years earlier. Britain was on the ascent. Surveying was the mathematics of empire. India, Britain's largest protectorate, had never been systematically mapped. The British East India Company needed to know what minerals, crops and commodities could be turned into profitable enterprises, where they were, and how to move them to ports. This depended on accurately mapping India. Infantry officer William Lambton proposed an audacious solution: measure the entire subcontinent with triangles.

Lambton was granted the commission, and on April 10, 1802, the Great Trigonometrical Survey (GTS) of India began with a humble but critical baseline from St. Thomas Mount near Madras, 12 km south to Perumbauk Hill. Everything depended on the accuracy of this first baseline: even the smallest error would multiply as triangles spread across the subcontinent. Perfection was essential. The distance was measured with a 100-ft steel chain protected from the sun beneath A-frame tents to prevent thermal expansion. It moved slowly, 100 ft at a time from start to finish. Every link mattered. The baseline took 57 days.

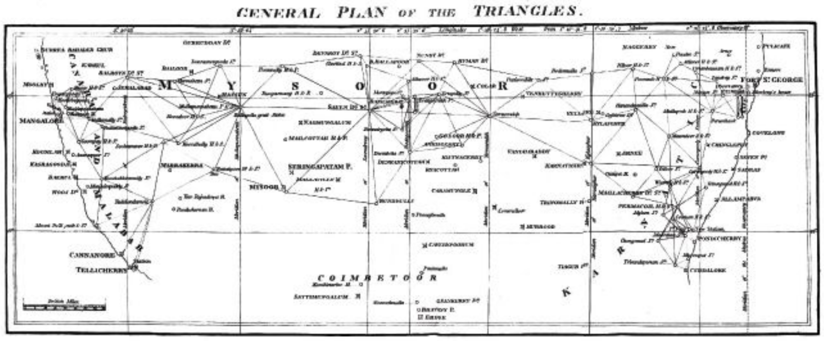

William Lambton

To guarantee perfect alignment, Lambton relied on a massive custom-built theodolite. It weighed 1,102 lbs, requiring 12 men to carry. Surveyors planted stakes, stretched strings, and used the theodolite to correct for every change in elevation, turning a simple chain measurement into the geodetic foundation of the entire survey.

Time marched on faster than the survey. The East India Company estimated five years, but by 1818, the survey reached west to Mangalore and north to Hinganghat. It was too slow. Lambton's vision of "an uninterrupted series of triangles… from sea to sea…to an unlimited extent in every other direction," a complete geometric quilt covering

"Surveyors planted stakes, stretched strings and used the theodolite to correct for every change in elevation, turning a simple chain measurement into the geodetic foundation of the entire survey."

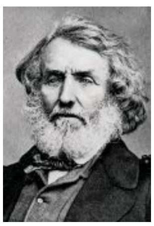
fotoVoyager / E+ / Getty Images



The map of triangles covered Madras to Mangalore.

India, proved implausible. Malaria took its toll. Lambton's health declined and in 1823 he died at Hinganghat. George Everest inherited the survey.

Everest recognized Lambton's dream of total coverage would take centuries. Instead, he conceived a "gridiron" of chains running north–south and east–west, intersecting at right angles, scaffolding to which localized surveys could be tied. The shift is evident on the GTS map: dense triangulation in south-central India reflects Lambton's ambition, while the more open, structural network elsewhere reveals Everest's pragmatism.


George Everest

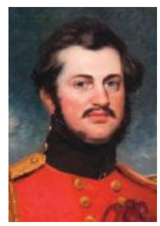
By the 1830s, Everest's survey party had grown into slow-moving caravans, reaching as many as 1,000 people at peak times. Contemporary accounts describe columns supported by elephants, horses and camels, with hundreds of porters carrying tents, instruments and provisions. The logistics were immense: scouts rode ahead to negotiate passage with villages, reapers with scythes gathered grass for the animals, hunters supplied fresh meat and a traveling treasury paid workers and suppliers. To villagers, an approaching column appeared like a military invasion. Negotiations for assistance and safe passage could halt the survey for days.

The survey's path was relentless. The Great Arc bisected India along the 78th meridian, from Cape Comorin to Bangalore, across the Deccan Plateau, through Hyderabad, over the northern plains to Dehra Dun at the Himalayan foothills. They didn't simply pass through. They stayed. Sometimes for weeks, building 50 ft masonry towers to mount the theodolites.

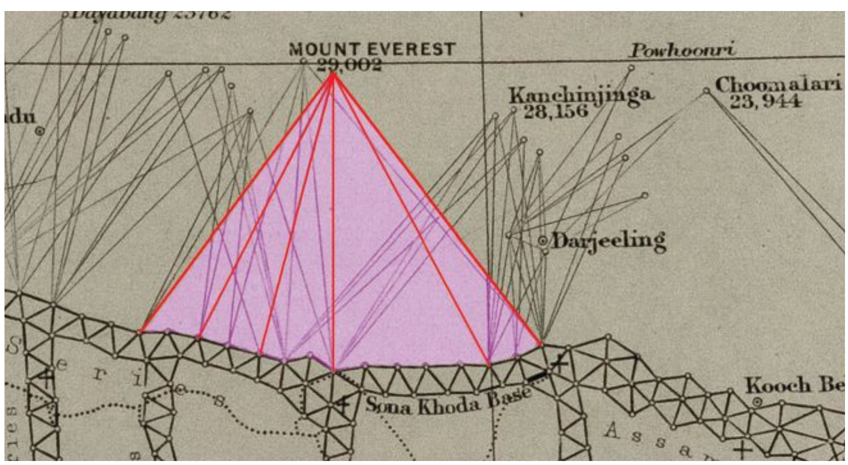
When daytime heat and haze made measurements impossible, Everest shifted to night surveying using powerful lanterns visible from 30 miles away. They constantly adapted due to temperature, atmospheric refraction, verification baselines measured at the chain ends. Every measurement propagated from that first line at Madras; a minor error would compound over thousands of miles.

The price was paid in lives. Malaria wiped out entire parties. Three officers died in the Terai, the malarial lowlands of northern India. Two more retired, health-shattered. Everest himself contracted malaria repeatedly, suffering partial paralysis. The climate, he wrote, was "very deadly."

The survey transformed the land. To achieve clear sight lines, villages were razed, sacred hills appropriated, and community supplies exhausted. Yet the work continued. In December 1841, almost 40 years since the GTS began, the 1,500-mile Great Arc was complete. The spine was in place. Everest retired in 1843, passing the work to Andrew Scott Waugh, who extended the gridiron eastward. Nepal and Tibet were closed to outsiders. Waugh understood the distant Himalayan peaks, more than a hundred miles away, would have to be measured from the border stations anchored to the GTS framework. Accuracy became even more critical. This shift in focus from Everest's large sprawling triangles inching north like a spider's web forming the Great Arc, to Waugh's tight triangles hugging the Himalayan frontier is visible on the GTS map.


Andrew Waugh

Over the next decade, Waugh's teams pushed eastward through the jungles of Bengal, Bihar and Orissa,



Royal Geographical Society

CLOSE-UP of the border survey stations used to observe Peak XV.

verifying baselines, fixing latitudes and longitudes astronomically, establishing stations that brought the peaks within mathematical reach. Along the entire border, surveyors recorded the peaks. To measure Peak XV, six observation stations were selected across the Terai, the deadly malarial lowlands chosen for the clear site lines to the summit. From these stations, surveyors recorded azimuth and elevation angles across multiple seasons. They measured the summit at sunrise, when the peak was first illuminated. None of the surveyors knew the height of the mountains they were observing because distance could not be measured directly. Only when all stations were plotted on a map could the peak's position be fixed and the elevation calculated. This high-level mathematics fell to the human computers in Calcutta, led by Radhanath Sikdar.

By 1851, Sikdar had risen to chief computer, directing the department that transformed field observations into verified measurements. The 1851 Survey Manual acknowledged his distinction: "Babu Radhanath Sickdar, the distinguished head of the Computing Department... whose intimate acquaintance with the rigorous forms and mode of procedure...render his aid particularly valuable." Yet, neither his education nor his geodetic calculation training prepared him for the complexities of the Himalaya problem. Nonetheless, he took the raw observations and calculated the mountains' heights to determine which, if any, of the distant peaks was truly the highest point on Earth.

Radhanath Sikdar

Sikdar calculated the height of each of the peaks. There were many. It was slow, meticulous work. Peak XV required more than standard calculation. Six observation stations produced six independent height measurements, each requiring corrections for atmospheric refraction (light bending through air layers of varying density and temperature), Earth's curvature (the summit was more than 100 miles away), and plumb-line deviation (the Himalayas' mass pulled survey instruments slightly toward the mountains).

Sikdar applied the Method of Least Squares, a statistical technique for extracting the most probable value from multiple observations. Each station's measurement carried uncertainty; combining all six through rigorous mathematics yielded a more reliable result.

The calculation took months. When Sikdar finished, he was stunned: exactly 29,000 ft recalculated and received the same result. The precision seemed too perfect. Sikdar knew the stakes. This wasn't just another mountain. His calculations were correct. Peak XV was the highest point in the world, Chomolungma, meaning the goddess mother of the Earth. Such a discovery demanded the honor of delivering the news in person.

In April 1852, Sikdar traveled 1,600 km from Calcutta to Dehra Dun. The journey took weeks. He carried the calculations in his satchel and the announcement in his mind.

When Sikdar burst into Waugh's office with the news, Waugh worried that exactly 29,000 ft (8,830 m) would make surveyors appear to have simply rounded. 2 ft were added, a small fiction to preserve credibility. The official height for Peak XV became 29,002 ft.

Waugh spent four years verifying before the official announcement in March 1856. The mathematics were sound from the moment Sikdar burst into that office. Then, 20 years later, the 1875 Survey Manual erased Sikdar's name entirely. The British press called it "robbery of the dead."

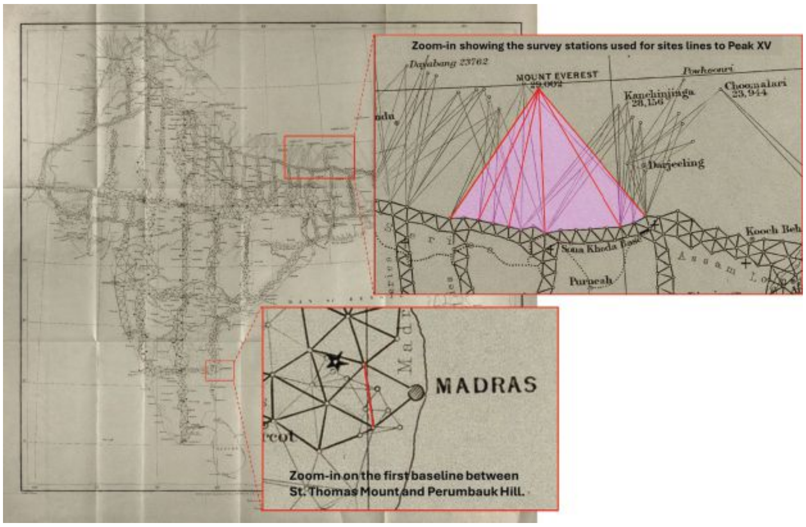
Station Name	Distance from Peak XV	Computed Height
Jirol	118 miles	28,991 ft
Mirzapur	108 miles	29,005 ft
Joafpati	108 miles	29,001 ft
Ladnia	108 miles	29,998 ft
Harpur	111 miles	29,026 ft
Minai	113 miles	28,990 ft

Sikdar's calculations have stood the test of time. The 1954 Survey of India measurement, 102 years later, yielded 29,028 ft, a minimal difference. In 1999, GPS technology placed a receiver on Everest's summit for the first time: 29,035 ft. The 2015 earthquake prompted the most comprehensive measurement yet.

On May 22, 2019, at 3 a.m., Nepali surveyor Khimlal Gautam departed Everest's South Col for the 10-hour climb carrying 90 lbs (41kg) of equipment. The pre-dawn timing avoided crowds: the weight included a Trimble R10 GNSS receiver and ground-penetrating radar to distinguish rock height from snow depth. Eight continuously operating reference stations (CORS) were positioned across Nepal to receive signals from GPS, GLONASS, Galileo and BeiDou. Chinese surveyors simultaneously measured from the north.

Gautam spent hours on the summit, collecting data while his body slowly consumed itself in the death zone. He lost a toe to frostbite. A team member nearly died from oxygen

> "The 1875 Survey Manual erased Sikdar's name entirely. The British press called it 'robbery of the dead.'"



Survey of India, via David Rumsey Collection

THE MAP of The Great Trigonometrical Survey.

depletion. Gautam understood, "Mount Everest symbolizes something in Nepal, but it's not only a Nepal asset, it's a world asset."

On Dec. 8, 2020, Nepal and China jointly announced their result, agreeing for the first time the height was 29,031.69 ft. Sikdar's error across 168 years was 31.69 ft, an accuracy of 0.11%.

From that moment in Dehra Dun, Sikdar, dusty from the road, calculations in hand, certainty in his voice, we trace backward through 50 years of framework building to understand what made that measurement possible. Peak XV, hidden in plain view, seen for hundreds of miles, refusing to be known, was finally measured.

Once we have measured it, we want to believe we know it, but the Indian and Eurasian tectonic plates continue to collide, pushing the mountain up four millimeters per year. Earthquakes in the region change the topography. The geoid problem persists: What does "sea level" mean 440 miles from the coast in a gravitationally dense region? Modern surveyors still grapple with the fundamental question: What does "height" mean when measured against a theoretical reference surface?

The Great Trigonometric Survey proved that surveyors could measure what they couldn't touch, calculate what they couldn't reach, and verify what they couldn't see. It required building the geodetic infrastructure across a subcontinent, maintaining mathematical precision across decades, and accepting brutal human costs.

Then, the computer was a man. The information was in his satchel. The message was delivered in person. It was the first time the height of the highest known point was determined not by a physical barometer on a summit, but by mathematics alone, a man solving equations in a room 440 miles away. Sikdar proved the impossible: What couldn't be touched could be measured, what couldn't be reached could be calculated, and a man dusty from the road could hold the height of the world in the palm of his hand.

Four names for one mountain. Each represents a different understanding. Its ancient name, Chomolungma, and Sagarmatha, its national identity.

> "Sikdar proved the impossible: what couldn't be touched could be measured."

Peak XV, its cartographic name marking the audacious attempt to measure it, and the name Mount Everest, the crowning achievement, a proclamation honoring mathematics, from Hipparchus who is credited with developing trigonometry to the computers, like Sikdar. It stands as a monument to all the surveying and cartography, especially of the 19th century accomplishing the impossible against extraordinary odds.

Surveying and mapping are jobs of courage and determination exploring the unknown, risking death in malaria-infested jungles, Everest working while stricken with partial paralysis, Abdul Hamid crossing a forbidden border, and Gautam's predawn climb. They all understood what mattered was worth the risk. It is the surveyor's call to arms: measure the Earth. 🌐

WILLIAM "BEAU" TEWELOW is a designated Geographic Information Systems Professional (GISP) and a 23-year Veteran of the U.S. Navy with more than 35 years of experience in geospatial applications covering communications, disasters, intelligence, military, meteorology, national airspace, and humanitarian relief efforts. Currently, he is a senior geospatial specialist contracting with FEMA.

He has a master's degree in Organizational Leadership, a bachelor's degree in Geospatial Intelligence Studies, and an undergraduate degree in Geographic Information Technologies.

In 2016, he was honored to be able to lead a national geospatial strategic intiative at the U.S. Department of Transportation under the authority of the White House Open Data Partnership. Since 2017, he has been writing for *Geospatial Magazine* and *GPS World*.

GPS GNSS POSITIONING NAVIGATION TIMING WORLD

2026 SIMULATOR BUYERS GUIDE

In our 15th annual Simulator Buyers Guide, we feature simulator tools, devices and software from six prominent companies that aid GNSS receiver manufacturers in product design.

SPIRENT FEDERAL SYSTEMS, NOW PART OF KEYSIGHT

EW & NAVWAR SIMULATION FOR MISSION ASSURANCE

Spirent Federal now combines its PNT and NAVWAR simulation expertise with Keysight's full-spectrum RF and EW portfolio. This alignment enables end-to-end mission assurance — from system design through NAVWAR and EW validation to operational performance testing.

NEW PNT Xe — ECONOMICAL, DEFENSE-GRADE SIMULATION

PNT Xe is an intuitive, cost-effective PNT simulator designed to expand test access and coverage for teams facing accelerated development deadlines. GPS M-code capability with unclassified AES-M is available for authorized users.

PNT X — NAVWAR & ASSURED PNT SIMULATION PNT X is an all-in-one system for comprehensive simulation across defense, NAVWAR and space applications.

Spirent PNT Simulation Systems	
Entry-level GNSS Simulation (AES M-Code capable)	PNT Xe (pictured)
Commercial Multi-constellation Simulation	GSS7000
NAVWAR and Assured PNT Simulation	PNT X
Wavefront Anti-jam Antenna Simulation	PNT X CRPA Test System
OTA Anti-jam Antenna Simulation	PNT X OTA Test System
NAVWAR Field Testing	PNT Xe (pictured)

SPIRENT FEDERAL SYSTEMS

PNT Xe – Desktop to NAVWAR field applications

Military Signals. Simulate true M-code using approved MNSA-encrypted signals, including RMP. AES-M and Y-Code are also supported.

Complementary PNT. Supports integrated GNSS+INS, sensor fusion, ALTNAV, LEO constellations and other emerging PNT sources.

Custom Signal Generation. Design fully customizable, non-SIS proprietary signals, experimental jamming waveforms and more — and generate any RF signal from an IQ file. PNT X applies dynamic motion, geometry and propagation effects to custom waveforms with a patented IQ spatial awareness tool.

Real-Time Dynamic 3D Environments. Embedded terrain modeling automatically applies multipath, diffraction and obscuration to all signals for operationally realistic testing.

CRPA (ANTI-JAM ANTENNA) SYSTEM TESTING

PNT X CRPA Test System. Test CRPA electronics with thousands of independent GNSS, jamming and spoofing signals for up to and beyond 30 antenna elements. A precise wavefront generated by unique phase alignment techniques, seamless calibration and a high jamming-to-signal (J/S) power ratio ensures accurate results no matter how extreme the test case.

PNT X OTA Test System. Bring antenna performance into the test. A patented zoned-chamber approach enables hours-long testing and full-system CRPA validation, with thousands of threat signals and terrain effects applied.

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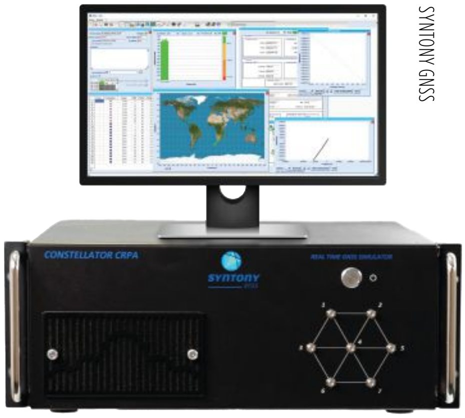
SYNTONY GNSS

CONSTELLATOR VERSION 5.0 EXPANDS GNSS TEST CAPABILITIES ACROSS BANDS AND MISSION PROFILES

The latest release of the Constellator GNSS simulator platform introduces broader bandwidth coverage and enhanced computational capacity to support increasingly complex test scenarios. Version 5.0 extends the system's ability to model complete RF and environmental conditions, integrating GNSS constellations, signals, propagation effects, and threat dynamics, including jamming and spoofing.



SYNTONY GNSS

Constellator CRPA 7 – element unit

Updated Hardware Platform

The updated **2U / 3 RF** platform is the most compact hardware configuration in the product line. Depending on licensing, it can generate all GNSS constellations, signals, and frequencies for single antenna testing, thus remaining scalable through software evolution on the same hardware base.

The updated architecture includes a next-generation processing unit, removable storage for restricted or classified workflows, and revised status indicators. The combined increase in RF bandwidth and processing throughput provides improved representativeness when simulating full mission environments.

Product Line Extensions for Advanced Use Cases

The expanded Constellator range now supports a wider set of configurations:

- **6 RF system,** with each path covering 200 MHz for scenarios involving multiple receivers, multiple antenna chains, or independent trajectories.
- **CRPA test configurations,** supporting 4 or 7 element-controlled radiation pattern antennas with phase synchronized operation across a 100 MHz bandwidth.
- **CRPA VXG C solution,** developed with Keysight, integrating four phase coherent channels and a 2.5 GHz instantaneous bandwidth allowing all GNSS signals to be generated through a single RF channel.

Application Areas

Constellator systems are used in electronic warfare evaluation, contested environment testing, and dynamic jammer/spoofer analysis.

In the space sector, the system has been used within **Final Assembly Line (FAL)** workflows, and more than 1,000 satellites currently in orbit have been tested using Constellator systems.

The system models space specific GNSS conditions such as Earth tangent signal geometries, ionospheric and tropospheric effects, masking, attenuation and transmitter antenna patterns. The added computing resources in Version 5.0 support scenarios with high satellite visibility and more detailed environment representation.

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SAFRAN ELECTRONICS & DEFENSE

ADVANCED SIMULATION FOR GNSS, LEO, JAMMING & CRPA

Safran delivers powerful, software-defined GPS/GNSS simulation through the Skydel Simulation Engine, offering unmatched flexibility, real time responsiveness, and future-ready performance. Safran's simulator family supports scenario based testing for all global constellations — including existing and emerging LEO PNT constellations — with realistic RF generation and advanced threat modeling.

The Flexibility of Skydel

Skydel is at the core of all Safran simulators. Its software-defined architecture provides full control over constellation selection, signal parameters, interference, trajectories and timing — allowing labs to rapidly build, automate and iterate on scenarios. Skydel supports all major global constellations and frequencies, delivers a 1000 Hz simulation iteration rate, and integrates jamming or spoofing without extra hardware.

Because it runs on COTS hardware and GPUs, users can even **build their own simulator,** scaling from benchtop systems to multi antenna or multi vehicle configurations.

Advanced Jamming and Spoofing (GSG 8 Gen2 Focus)

For threat-rich scenarios, **GSG 8 Gen2** delivers industry leading jamming and spoofing realism. Its GPU accelerated architecture allows generation of thousands of signals, real-time synchronized interference, multipath, and advanced spoofing waveforms — without requiring additional hardware. It supports simultaneous multi-band jamming, multi-antenna/vehicle scenarios, and complex attacker trajectories. GSG 8 Gen2 is also capable of LEO PNT interference simulation, reflecting modern NAVWAR challenges.

CRPA Resilience

Safran has CRPA testing solutions whether you are performing conducted or over-the-air (OTA) testing: The GSG Wavefront and GSG Anechoic platforms are both powered by Skydel. GSG-Wavefront simulation provides phase coherent RF outputs for CRPA beamforming evaluation, while the GSG-Anechoic allows chamber setups for OTA directional testing. Skydel's multi antenna synchronization, high fidelity modeling, and advanced interference generation allow labs to characterize CRPA behavior under dynamic jamming/spoofing threats and multi path conditions.

safran-navigation-timing | sales@nav-timing.safrangroup.com

SAFRAN

ROHDE & SCHWARZ

GNSS SIMULATORS FROM THE T&M EXPERT

GNSS simulators from Rohde & Schwarz can generate signals from all operational satellite-based navigation systems, including GPS, GLONASS, Galileo and BeiDou, with emulation of high-precision GNSS, SBAS and QZSS. Simulation capabilities include accurate modelling of satellite orbits, including orbit errors and perturbations, as well as other typical error sources such as ionospheric and tropospheric effects and satellite clock errors. We enable GNSS receiver testing for all kinds of applications from aerospace and defense to cellular and automotive, including autonomous driving, UAVs, transportation, aviation, farming, financial services, disaster management, security services and scientific research.

R&S SMBV100B Midrange GNSS Simulator

The R&S SMBV100B can simulate signals from all important GNSS constellations and frequency bands in parallel. Using its integrated simulation software, even complex GNSS scenarios can be configured in an easy, user-friendly and efficient way. This includes realistic modeling of GNSS orbits, signal propagation effects, and system errors, as well as realistic modeling of the user environment. Typical GNSS receiver tests include the determination of the receiver's time to first fix, acquisition and tracking sensitivity, reacquisition time and its ability to provide an accurate positioning solution. In addition, it is often required to test the receiver's performance under special conditions or in dedicated environments such as interference or multipath environments or under the influence of atmospheric effects and dynamic stress.

ROHDE & SCHWARZ

R&S SMW200A High-End GNSS Simulator

The R&S SMW200A is the Rohde & Schwarz solution for high-end GNSS testing. In addition to all features of the midrange solution, it can generate GNSS signals for any desired coexisting or interfering signal simultaneously. To address adaptive antenna array testing applications — such as CRPA — multiple SMW200As can be coupled and operated as a single setup. This allows CRPA DUTs with four or more antenna elements to be tested. Thanks to the scalable approach, the system can be extended by additional instruments in case more RF ports are required.

- Find out more about GNSS simulators from Rohde & Schwarz: rohde-schwarz.com/automotive/satellite-navigation-testing
- Download your satellite navigation pocket guide: rohde-schwarz.com/satellite-testing/pocket-guide

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LABSAT

TEST ANYWHERE WITH LABSAT

LabSat GNSS simulators deliver multi-constellation, multi-frequency testing that is reliable, repeatable and consistent. With a one-touch Record and Replay feature, LabSat offers an efficient, cost-effective solution for GNSS receiver testing and development.

LabSat 4 – Advanced Testing with Precise Customization

LabSat 4 features three individually configurable RF channels with selectable quantization up to 12-bit I&Q and bandwidth up to 60 MHz, giving engineers precise control over recordings and file sizes.

Additional capabilities include external data integration via CAN, CAN-FD and RS232; digital event capture; saveable custom record settings; and multi-system synchronization for dual-antenna testing. A user-friendly web-based interface simplifies configuration and operation.

When timing is critical, LabSat 4 pairs with SatGen to deliver real-time GNSS signals stamped with the current UTC time, enabling precise validation of time-sensitive systems.

LABSAT

LabSat 4 and SatGen – Advanced testing with precise customization to NAVWAR field applications

SatGen Simulation Software

SatGen GNSS Simulation Software gives LabSat users the freedom to build fully custom scenarios, defining position, route, speed, date and time to simulate virtually any location in the world.

Supporting all signals across the upper and lower L-band, including GPS L1C and BeiDou third-generation signals, SatGen generates GNSS RF I&Q or IF scenario files that transfer seamlessly to LabSat for replay.

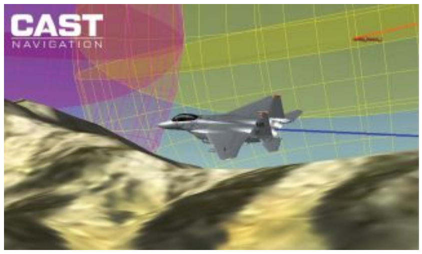
Route creation is straightforward, with tools for road, pedestrian and rail navigation using Google Maps, Bing Maps, or OpenStreetMap. The intuitive interface makes it easy to create scenarios, view almanac data and edit visible satellites. Scenarios also can be queued and run consecutively, streamlining the test workflow.

labsat.co.uk | sales@labsat.co.uk

CAST NAVIGATION, NOW PART OF SPIRENT FEDERAL

CAST Navigation's suite of simulator solutions delivers precision, accuracy and repeatability. From simple integration testing to complex mission simulations, CAST Navigation solutions scale to meet user requirements.

Powered by multi-frequency, multi-constellation GNSS and interference signal-generation technology, CAST Navigation simulators provide coherent, highly accurate and fully programmable signals. Advanced, configurable vehicle trajectory capabilities meet project requirements ranging from antenna testing to simulations of squadrons maneuvering in contested environments.



CAST NAVIGATION

Intuitive Graphical Interface

Intuitive Graphical Interface

A comprehensive and intuitive graphical interface unifies all simulator capabilities so users can configure complex simulation scenarios quickly. For example, CAST Navigation simulators can model many vehicle types with static and dynamic motion profiles: airborne, terrestrial, aquatic or space-based. Using configured scenario profiles or vehicle truth data, CAST Navigation simulators create high-dynamic, six-DOF real-time trajectories.

High-Fidelity Simulations of Real-World Conditions

CAST Navigation solutions can reproduce terrain, sea-state and atmospheric effects to simulate missions with high fidelity. Jamming capabilities recreate natural, urban and hostile interference to produce precisely controlled waveforms with high output power and exceptionally low intermodulation noise.

IMU Modeling and Simulation

CAST-Inertial provides the customer with the powerful ability to properly stimulate INS and GNSS/INS navigation systems.

The CAST systems produce GNSS RF signals and IMU sensor data that provide a fully dynamic simulation capability. Customizable and expandable solutions will allow configuration of the GNSS/INS system to meet current and future requirements.

Multi-Frequency, Multi-Constellation Simulations

The GPS/GNSS simulators generate accurate, programmable signals to each antenna element with up to 16 satellites in view from as many as four constellation types. GPS simulations can generate any positioning signal (C/A-code, P-code, Y-code, SAASM, M-code AES and M-code MNSA).

Modular, Scalable Solutions

Proprietary synchronization technology configures customer solutions with multiple simulator capabilities — GPS/GNSS, inertial, jamming and CRPA. As those needs evolve, these solutions do not become obsolete. Rather than replace a functioning system, customers can rely on modular architecture to meet their new requirements.

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SPACE & EARTH

NASA / JPL-Caltech / MSSS

NASA's Perseverance Mars rover took this selfie, made up of 62 individual images, on July 23, 2024. A rock nicknamed Cheyava Falls is to the left of the rover near the center of the image.

NASA's Perseverance Doesn't Need GNSS to Find Itself on Mars

Imagine you're all alone, driving along in a rocky, unforgiving desert with no roads, no map, no GPS, and no more than one phone call a day for someone to inform you exactly where you are. That's what NASA's Perseverance rover has been experiencing since landing on Mars five years ago. Though it carries time-tested tools for determining its general location, the rover has needed operators on Earth to tell it precisely where it is — until now.

A new technology developed at NASA's Jet Propulsion Laboratory in Southern California enables Perseverance to figure out its whereabouts without calling humans for help. Dubbed Mars Global Localization, the technology features an algorithm that rapidly compares panoramic images from the rover's navigation cameras with onboard orbital terrain maps.

Running on a powerful processor that Perseverance originally used to communicate with the Ingenuity Mars Helicopter, the algorithm takes about two minutes to pinpoint the rover's location within some 10 in (25 cm). Mars Global Localization was first used successfully in regular mission operations on Feb. 2, then again Feb. 16.

"This is kind of like giving the rover GPS. Now it can determine its own location on Mars," said JPL's Vandi Verma, chief engineer of robotics operations for the mission. "It means the rover will be able to drive for much longer distances autonomously, so we'll explore more of the planet and get more science. And it could be used by almost any other rover traveling fast and far."

The upgrade is especially valuable given how well Perseverance's auto-navigation self-driving system has been working. Enabling the rover to re-plan its path around obstacles en route to a preestablished destination, AutoNav has proved so capable that the distance Perseverance can drive without instructions from Earth is largely limited by the rover's uncertainty about its whereabouts. Now that it can stop and determine its exact location, Perseverance can be commanded to drive to potentially unlimited distances without calling home.

Implementation of Mars Global Localization comes on the heels of another innovation from the Perseverance team: the first use of generative artificial intelligence to help plan a drive route by selecting waypoints for the rover, which are normally chosen by human rover operators.

Beyond Visual Odometry

Unlike on Earth, there is no network of GPS satellites in deep space to locate spacecraft on planetary surfaces. Missions must come up with other ways to determine their location.

The Mars Global Localization algorithm runs on a fast commercial processor in the Helicopter Base Station. Perseverance used the base station to communicate with the now-retired Ingenuity Mars Helicopter.

As with NASA's previous Mars rovers, Perseverance tracks its position using visual odometry, analyzing geologic features in camera images taken every few feet while accounting for wheel slippage. As tiny errors in the process add up over the course of each drive, the rover becomes increasingly unsure about its exact location. On long drives, the rover's sense of its position can be off by more than 100 ft (up to 35 m). Believing it may be too close to hazardous terrain, Perseverance may prematurely end its drive and wait for instructions from Earth.

"Humans have to tell it, 'You're not lost, you're safe. Keep going,'" Verma said. "We knew if we addressed this problem, the rover could travel much farther every day."

After each drive comes to a halt, the rover sends a 360° panorama to Earth, where mapping experts match the imagery with shots from NASA's Mars Reconnaissance Orbiter (MRO).

SEE NASA, NEXT PAGE. >>

NASA

<< *Continued from previous page.*

The team then sends the rover its location and instructions for its next drive. That process can take a day or more, but with Mars Global Localization, the rover is able to compare the images itself, determine its location, and roll ahead on its preplanned route.

"We've given the rover a new ability," said Jeremy Nash, a JPL robotics engineer who led the team working on the project under Verma. "This has been an open problem in robotics research for decades, and it's been super exciting to deploy this solution in space for the first time."

The small team began working in 2023, testing the accuracy of the algorithm they'd developed using data from 264 previous rover stops. The algorithm compared rover panoramic photos to MRO imagery and correctly pinpointed the rover's location for every single stop.

How Ingenuity Helped

Key to Mars Global Localization is the rover's Helicopter Base Station (HBS), which Perseverance used to communicate with the now-retired Ingenuity Mars Helicopter. Equipped with a commercial processor that powered many consumer smartphones in the mid-2010s, the HBS runs more than 100 times faster than the rover's two main computers, which, built to survive the radiation-heavy Martian environment, are based on hardware introduced in 1997.

The Ingenuity mission was able to risk employing more powerful commercial chips in the HBS and the helicopter even though they hadn't been proven in space. It paid off: Expected to fly no more than five times, the rotorcraft completed 72 flights.

The power of the HBS processor inspired Verma to look for ways the Perseverance mission might harness it. "It's almost like a gift. Ingenuity blazed the trail, proving we could use commercial processors on Mars," Verma said.

Tapping into the HBS computer has had its challenges. To address reliability, the team developed a "sanity check": The algorithm runs on the HBS multiple times before one of the rover's main computers checks to ensure the results match. During testing, the team repeatedly found the rover's position was off by 1 mm. They discovered damage to about 25 bits — a minuscule fraction of the processor's 1 GB of memory — and developed a solution to isolate those bits while the algorithm runs.

The team's sanity check and memory solutions are expected to find new uses as faster commercial processors are employed in future missions. The team already has turned its sights to the Moon, where difficult lighting conditions and long, cold lunar nights make knowing exactly where spacecraft are located all the more critical. 🌐

SPACE & EARTH

Ultra-Low-Noise Amplifiers Achieve In-Orbit Milestone on ESA HydroGNSS Mission

Ultra-low-noise amplifiers developed by European Engineering Consultancy Ltd. (EECL) are operating in orbit on the European Space Agency's (ESA's) HydroGNSS mission, marking a technical milestone for the hardware following the satellites' launch in November 2025.

HydroGNSS consists of two small satellites designed to measure hydrological and climate-related variables using GNSS reflectometry. The satellites collect signals transmitted by navigation satellites such as GPS and Galileo and analyze those signals after they reflect from Earth's surface. The reflected signals provide data on environmental parameters including soil moisture, freeze–thaw conditions in permafrost regions, wetlands and inundation, and aboveground biomass.

The satellites were launched aboard a SpaceX Falcon 9 rideshare mission from Vandenberg Space Force Base in California on Nov. 28, 2025. The mission is part of the European Space Agency's Scout program, which focuses on relatively small and cost-effective Earth observation satellites designed to demonstrate new measurement techniques.

EECL designed and manufactured six multiband ultra-low-noise microwave amplifiers used in the spacecraft payload. The amplifiers are part of the radio-frequency front end of the receiver system and are designed to amplify very weak reflected GNSS signals while minimizing additional noise, helping preserve signal quality for scientific analysis.

Early on-orbit results indicate the satellites' payloads are functioning as expected. Both spacecraft have begun collecting delay-Doppler maps of reflected GNSS signals, an early step in commissioning that confirms the receivers are acquiring and processing signals properly.

The HydroGNSS satellites were built by Surrey Satellite Technology Ltd., which also developed the GNSS receiver used on the mission. The spacecraft operate in low-Earth orbit and are phased apart to increase global coverage of the measurements.

ESA

DEFENSE

Finland Seeks to Criminalize Unauthorized Possession of GNSS Jammers

On Feb. 19, the Finnish government submitted a legislative proposal to parliament to criminalize possession and import of radio-frequency jammers and spoofers, including those blocking GNSS signals

According to Ministry of Transportation and Communications, the amendments would be made to the Act on Electronic Communications Services. The government proposes to amend the provisions on equipment that jam or spoof radio communications.

Unauthorized use of jammers already is banned. The government proposes to criminalize unauthorized possession of jammers, enabling confiscation and improving the authorities' ability to intervene in the unauthorized possession and import of such devices. The proposal would introduce a distinct definition for jammers, separate from radio equipment, allowing for stricter regulation.

The amendment would set clearer conditions for the use and possession of jammers for the authorities and other authorized parties. The possession and use of jammers for research and product development would be permitted under a license if certain conditions are met.

The proposal would also introduce exceptions for NATO and its member states regarding the right of the Finnish Transport and Communications Agency (Traficom) to check radio equipment or jammers and confiscate them for inspection.

Parliament will first hold a plenary debate on the government proposal. The proposal will then proceed to a committee reading. Following the committee report, the debate will continue in a plenary session.

The Act is scheduled to enter into force on July 1.

TRANSPORTATION

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GNSS Jamming in the Gulf Throws Ships Off Course

About 1,000 commercial vessels operating in the Gulf and Gulf of Oman have experienced serious GNSS disruption within a single 24-hour period following the outbreak of hostilities between Iran, the United States and Israel, exposing critical vulnerabilities in maritime positioning and timing as regional conflict intensifies. Experts say many shipboard receivers are still locked to legacy GPS-only L1 C/A signals, leaving crews to fall back on radar and visual navigation as jamming and spoofing events multiply across one of the world's most vital energy corridors.

Large-scale GNSS Disruption in Gulf Shipping

According to analysts quoted by AFP, roughly half of the 2,000 vessels in the broader Gulf region have at times been unable to reliably determine their position since the onset of US-Israeli strikes tied to the current Iran conflict. The majority of affected ships are operating off the coasts of the United Arab Emirates and Oman, where interference has rendered GNSS fixes intermittent or unusable for periods ranging from moments to hours.

Subsequent analysis shows the jamming pattern has expanded, with at least 21 to 30 jamming "clusters" now identified across the Gulf of Oman and Middle East Gulf, and daily interference events rising into the hundreds.

Specialists note that many bridge systems on commercial ships still rely on the original civilian GPS L1 C/A signal and do not track newer GPS L5 or regional alternatives such as Galileo or BeiDou, unlike modern smartphones that routinely fuse signals from multiple GNSS constellations and frequencies. Todd Humphreys of the University of Texas at Austin told AFP that most shipborne receivers "only listen" to legacy L1 C/A, and that aviation-certified receivers are even further behind, unable to process any signals beyond that band.

Operational Impacts and Safety Risks

The current wave of interference is coinciding with a sharp slowdown in tanker and container transits through the Strait of Hormuz, a chokepoint that normally carries around one-fifth of global oil and gas trade. Maritime security centers report hundreds of GNSS disruption events in 24-hour periods, alongside vessel attacks and the withdrawal of war-risk insurance, pushing some operators to reroute or suspend voyages.

On the bridge, loss of reliable GNSS does more than disrupt the electronic chart display: shipboard clocks, radar timing and speed logs can all depend on GNSS-derived timing, further complicating navigation in congested waters. Masters report reverting to "20th-century instruments" such as radar plotting and visual bearings on landmarks to maintain situational awareness, particularly near coastal approaches and traffic separation schemes.

The scale of the disruption is accelerating industry discussions around GNSS resilience, including multi-constellation, multi-frequency receivers, inertial navigation integration and complementary technologies based on Earth's magnetic field or terrestrial signals. Start-ups are field-testing alternative PNT concepts for both maritime and aviation users, but experts caution that widespread deployment on large commercial fleets remains years away.

For now, ship operators in the Gulf are being urged by security advisories to assume degraded GNSS, harden procedures against spoofing, and ensure crews remain proficient in traditional navigation techniques as the region becomes a live test case for operating with unreliable satellite positioning.

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SEEN & HEARD

NEW INSIGHTS INTO ARCTIC SEA ICE

Research drawing on data from Spire Global's GNSS-R constellation has enabled generation of Arctic-wide sea ice maps, marking a major step forward for GNSS-R. The research — enabled by the European Space Agency — suggests harnessing GNSS-R signals could become an important complement to established ice-monitoring altimetry missions. The study leveraged Spire's GNSS-R data to retrieve sea ice freeboard measurements across an entire winter season. The results show strong alignment with established altimetry datasets, including the ESA's CryoSat mission.

RUSSIAN JAMMING GOES TO THE DOGS

Military jamming and spoofing from Russia's Kola Peninsula interfered with GNSS trackers on dog sleds in Europe's longest sled race, the 1,200-km Finnmarksløpet, held in Norway in March. The electronic warfare degraded GPS signals, forcing the mushers to rely more on trail markings and use traditional compasses and maps. Event organizers, who provided a live tracking system for fans, found it difficult to follow along, but the racers finished without incident.

HISTORICAL PHOTOS FIND THEIR PLACES

Michigan Technological University is examining 11,000 historical images of the state's Upper Peninsula to find precisely where each photographer stood to take the photo. According to university GIS data librarian Bob Cowling, the location will provide richer information about a place's surroundings, especially if structures or environmental landmarks are no longer present. Donated historical images often arrive without any dates or location information attached to them. The project will make them easier to find on a map and make it possible to visualize what was there in the past.

TÜRKIYE ESTABLISHES EARTHQUAKE MONITORING

In February 2023, a devastating 7.8-magnitude earthquake struck near the Türkiye-Syria border, followed by a second nearly as strong. Six Turkish universities have launched TR-TRAK-GNSS, a real-time geodetic monitoring network to trace earthquake-related ground deformation across Thrace and the Southern Marmara region. The 28-station system is expected to evolve into a major scientific and early-warning system for earthquakes. Once fully deployed, it will form a continuous monitoring ring encircling Thrace and Southern Marmara.

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