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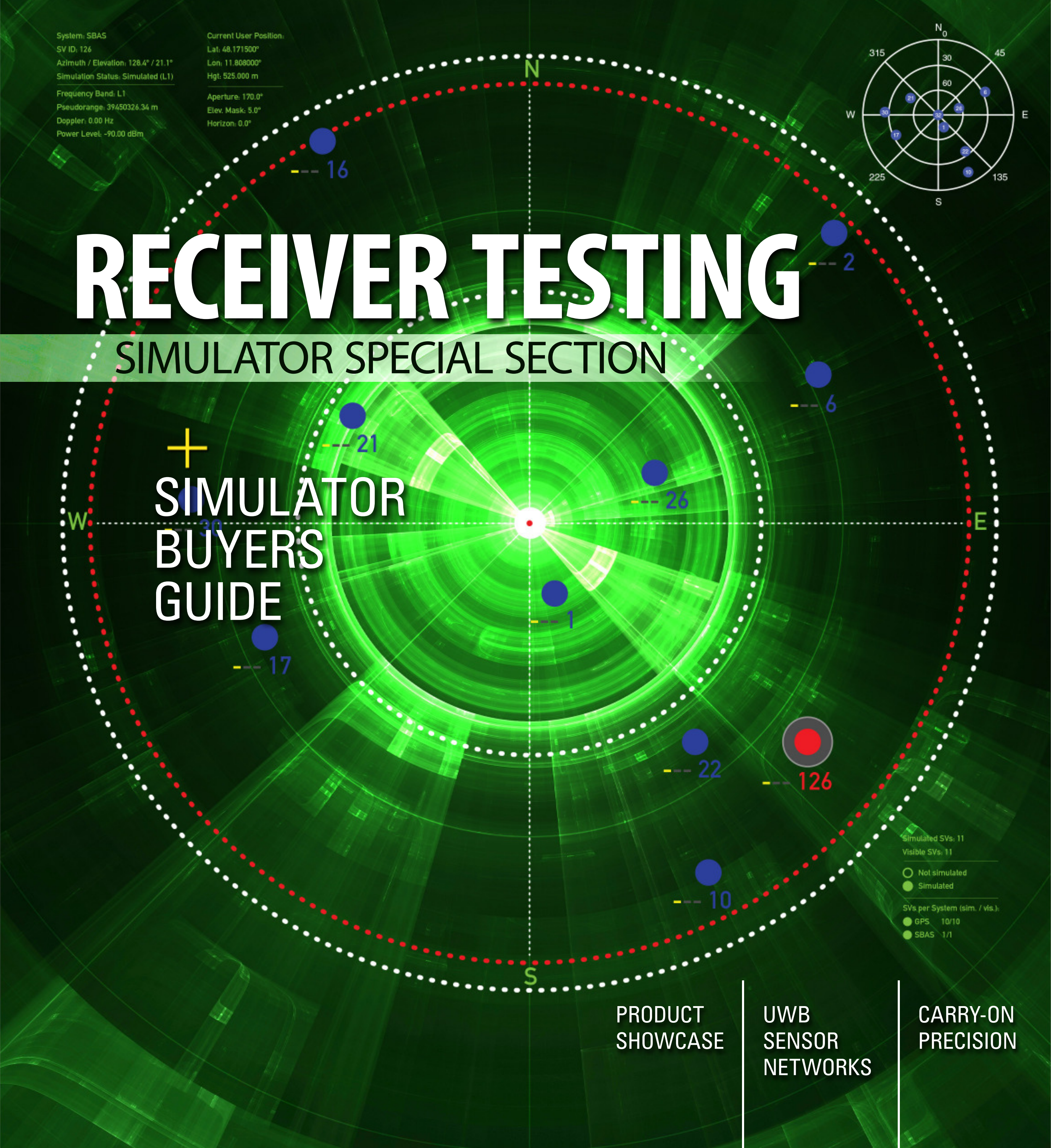
MARCH 2015



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March 2015
VOL. 26, NUMBER 3
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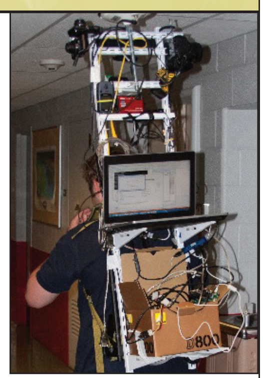

GPS III and the Budget Blues

Guest column by Don Jewell, Defense Editor

In the 2016 President's Budget, submitted in February, the U.S. Air Force requested a budget of $122.2 billion. That exceeds the Office of Management and Budget's recommendation by almost $10 billion. I applaud the Air Force action and think it may be too little, too late.

On the satellite or hardware side of the house, GPS III has problems centering on development and delivery issues with a subcontractor. In this case, however, the whole satellite program is not failing; just a component, albeit an important one: the Mission Data Unit or MDU.

For GPS III+, the Air Force plans for a two-phased competition process: a Production Readiness competition for up to three firm-fixed price contracts to mature competitors' production designs for a competition in a full and open competition for up to 22 GPS III Production SVs [satellite vehicles] with an expected award in FY17/18.

This sounds great if you need an entirely new GPS III system, which consists of, at a minimum, a new payload, satellite, launcher and ground C2 system. OCX is only designed to work with current and planned GPS SVs, and it doesn't even do that today. In fact, the government only needs an MDU, a critical part of the payload. Failure to produce the MDU on time has delayed GPS III by 18 months to date.

More troubling to me are the phrases from the government plan that essentially mean "We are going to pay competitors to mature their technology so they can compete against the current prime (LMCO), who is building the first 10 GPS III satellites." The government is saying the competitors on their own cannot compete against LMCO so we, the government, are going to give them contracts and lots of money to help them get to a point where they can compete, and then we are going to have a recompetition.

This will to take at least three years and cost hundreds of millions of dollars, and LMCO may well win again in the end, but at least we will have conducted a competition. Does this make sense?

Will the U.S. Air Force initiate a competition to acquire an entirely new GPS III SV, or fix the problem with the current GPS III program, the MDU? It appears the Air Force is looking to pursue an entirely new GPS III system to include SVs.

A significant added cost to the GPS budget concerns the need for a new ground C2 system if the total new systems approach is taken. If preliminary elements of the GPS space segment are developed without cross-checking the impact to the GPS control segment, technical, operational, budgetary and schedule impacts will be significant.

The already troubled next-generation GPS ground control system, OCX, budget likely has not considered the integration costs of a newly developed, yet-to-be-procured GPS III+ SV. OCX today is geared for the GPS III already contracted for, and it is failing to meet that challenge in a spectacular and expensive way. It is possible, even probable, that OCX integration costs for yet another new model of GPS III family of satellites would increase the OCX budget significantly — unless one assumes that the Air Force acquires a perfectly matched new satellite that integrates seamlessly with OCX.What are the chances of that, and why would you spend hundreds of millions of scarce acquisition dollars to procure an exact and more expensive replica?

Budget constraints are tight and getting tighter, mandating the Air Force "do more with less" in every context. For GPS III SVs, this means developing an alternate MDU rather than buying a new block of GPS SVs.

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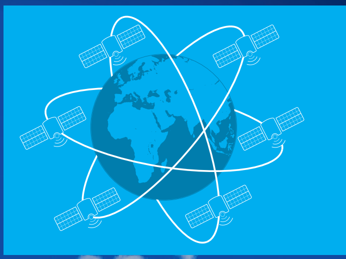
Gain perspective in real-world GNSS simulation



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Leap Second Confusion

The United States Civil GPS Service Interface Committee (CGSIC) has issued a notice about a problem some receivers are having implementing the correct time. The U.S. Coast Guard Navigation Center has received reports of synchronization issues since the implementation of a leap second on Jan. 21. Users experiencing this problem should contact the receiver manufacturer for a firmware or software update. Here is the text of the CGSIC notice:

All CGSIC: 2015 GPS Future Leap Second Implementation

The GPS 50 bit-per-second navigation message transmitted by each GPS satellite (specifically Page 18, subframe 4) includes the parameters needed to relate GPS time to UTC (Coordinated Universal Time). That relationship is maintained through leap second implementation transitions by IS-GPS-200 compliant user equipment. For leap second transition, user equipment must utilize the notice regarding a scheduled future delta time due to leap seconds (ÄtLSF), together with the week number (WNLSF) and the day number (DN), at the end of which the leap second becomes effective.

On or about Jan. 21, 2015, those GPS navigation messages began to include futurevleap second data which indicates an increase in the leap second to become effective at the end of June 2015. IS-GPS-200 revision H, dated 24 Sep 2013 paragraph 20.3.3.5.2.4 Coordinated Universal Time (UTC), documents the appropriate algorithm details to ensure correct utilization of the parameters above (including all potential truncated week number transitions and variations in time of processing relative to satellite upload timing near the future leap second effectivity).

The data upload for the June 30 leap second, initiated with SVN48/PRN07 at 18:33:56z on Jan. 21, was correctly executed. However, there are several receivers brands/models that seem to be mishandling this information and applying the leap second now. This is creating a negative one-second offset in faulty receivers. The U.S. Coast Guard Navigation Center has reports of these receivers causing synchronization issues with radios, computer systems, and data logging equipment.

Users experiencing issues with GPS receivers that began on Jan. 21 should contact the receiver manufacturer to determine if the latest firmware or software patch can correct the issue.

Galileo FOC Three and Four Fit to Fly

The third and fourth Galileo Full Operational Capability (FOC) satellites are a confirmed "fit" for their Arianespace Soyuz launch March 27, having made initial contact with the mission's dual-payload dispenser in French Guiana, according to Arianespace.

The fit check was completed over a two-day period inside the Spaceport's S1A payload preparation building. The two satellites were installed separately, with the Flight Model #3 (FM3) spacecraft integrated on — and subsequently removed from — the dispenser on Feb. 9. Flight Model #4 (FM4) underwent the same process the following day.

The payload dispenser for Galileo was developed by RUAG Space Sweden for Arianespace, and carries one satellite on each side. It will deploy the spacecraft during the Soyuz launch by firing a pyrotechnic separation system to release them in opposite directions at the orbital insertion point.

Final integration on the dispenser will be performed during upcoming processing at the spaceport, and will be followed by the completed unit's installation on Soyuz.

The March 27 mission — designated Flight VS11 in Arianespace's numbering system — will be the company's fourth launch carrying spacecraft for the Galileo constellation.

Air Force Orders Two More GPS III Satellites

The United States Air Force plans to order two more GPS III satellites from contractor Lockheed Martin. Lockheed Martin is under contract to build eight GPS III satellites, with the first planned to be launched in 2016. The contract includes options for up to four more satellites.

However, the Air Force plans to open up construction of subsequent GPS satellites for competitive bidding with GPS III space vehicle 11. The satellites are part of the Air Force's $167.3 billion budget request for fiscal 2016, up from $152.8 billion provided by Congress for fiscal 2015.

The Air Force also intends to buy only one GPS satellite — from Lockheed Martin or a different contractor — in 2017 rather than the three included in the current budget blueprint.

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SIMULATORS

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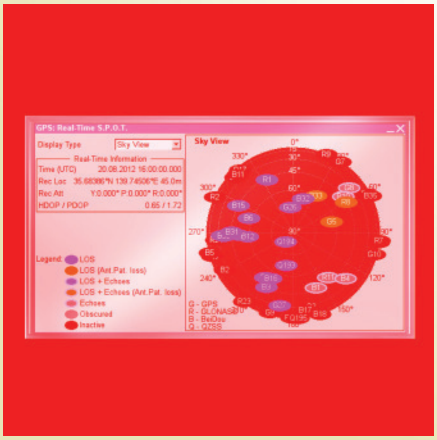

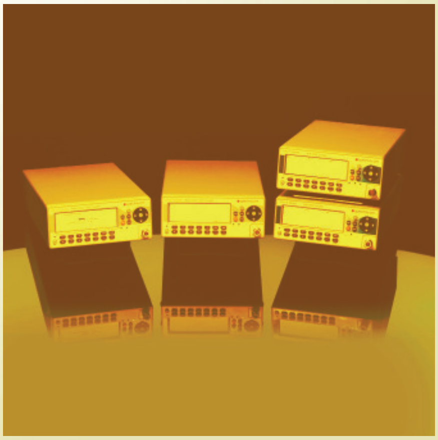

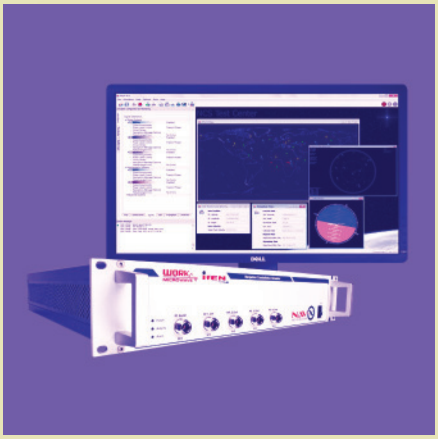

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A Leap into the Unknown?

Mark Sampson

A Leap Second will be introduced this year at 23:59 on June 30. This phenomenon comes around periodically and is necessary for keeping Coordinated Universal Time (UTC) in line with the small vagaries of the Earth's slowing rotation. Although it is an event that will pass unnoticed by the majority of people, it has implications for anyone involved in the development of GNSS-enabled devices. For some, it can be the cause of a major headache.

It has already happened this year: on January 21, GPS signals started to include information which effectively announced this year's leap second event, with the relevant data for future delta time, and week and day numbers. This caused issues with some receivers that weren't expecting it: some units applied the additional second immediately. It would be interesting to see how these systems might have reacted during an actual leap second transition.

Receiver logic flow requires

One school of thought holds that leap seconds should be abandoned, and that we should stick to atomic time from now on. Their removal would mean that by 2100, the Earth's rotation would be some two to three minutes behind humanity's precise, atomic-powered, 24-hour clock, and half an hour or so by 2700.

The World Radiocommunication Assembly, which has control over such matters, had been postponing a decision on whether to abolish the leap second for over a decade;

The behavior of a new receiver when subjected to a leap second may prove critical in certain instances, and without robust characterization it can lead to inconsistent performance.

Part of the problem with the leap second is its irregularity. Occurring every two or three years, it means that receiver technology moves on in between — and because the Earth's slowing rotation is not at a constant rate of change, it cannot be predicted when the next one will be announced. A rapidly developing market of GNSS products having to deal with random alterations to its time framework is not an ideal situation. Suitable preparations, clearly, should be employed.

The behavior of a new receiver when subjected to a leap second may prove critical in certain instances, and without robust characterization it can lead to inconsistent performance.

testing so that any GPS receiver can remain compliant with the IS-GPS-200 standard, and potential problems must be mitigated and controlled. The use of a GNSS simulator — which outputs a scenario containing the leap second event — allows for the receiver and any systems around it to be exercised over and over again, ironing out any anomalies, to ensure total reliability.

The recent issues with those non-compliant GPS engines highlights the advantage that simulation provides. The consistency it delivers enables a very thorough testing schedule, which will in turn lead to a straightforward application of the time change.

another vote is due this year. It wouldn't be any great wonder if this prevarication continues, so whilst it still exists, it is best to concentrate on what this June's extra second might have in store for anyone currently developing a GNSS product. Armed with a simulator, the unpredictability of leap second scheduling should no longer be a major concern. Should this year's vote be again inconclusive, those who have taken the positive step of acquiring a GNSS simulator will be in good shape to deal with the next time the clocks show 23:59:60.

MARK SAMPSON is LabSat product manager for RaceLogic.

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Successful Testing — and Why It Is More Important Than Ever

John Pottle and Neal Fedora

Precision matters. While "accuracy" is somewhat one-dimensional, "precision" is multi-faceted. We submit to you that whatever area of GNSS-based location you are interested in, precision matters today and will matter more in future. In this column, we'll explain why this is.

> The stakes for attacks on GNSS technologies are rising as incidents increase from occasional, often accidental, interference to more structured and organized approaches to jamming and even spoofing.

Traditional test approaches involve taking measurements to evaluate fundamental performance, for example, time-to-first-fix. As the number of critical applications that rely on positioning, navigation and timing (PNT) increases, the list of considerations for testing also grows.

Critical applications typically require higher integrity. There are a myriad of techniques to achieve this, from adding constellations, additional frequencies, improved navigation message authentication approaches and everything in between. Examples of safety-related applications include rail, connected car and aviation. Commercially critical application examples are smartphone payment authentication and container port automation. Protecting the warfighter and ensuring mission success against growing interference and jamming are key initiatives for the military. All of these applications are becoming more sophisticated and complex, stressing the importance of precision in testing.

Testing these critical applications requires:

- Precise and clear test objectives
- Precise definition of test approaches to explore both nominal and off-nominal conditions
- Comprehensive test tools that include all required signal components precisely modeled and controlled
- Test signal precision of at least an order of magnitude better than the device under test
- Results analysis that can quickly and effectively highlight areas of interest or concern.

Robustness against Cyberattacks. The second area calling for more precision is the need for a more robust PNT systems in the face of increasing cyber attacks and interference. While well known in the IT world, the GNSS community is relatively unfamiliar with being targeted by hackers. Attacks on GNSS technologies are increasing in frequency and sophistication for both commercial and military users. The stakes are rising as the incidents increase from occasional (often accidental) interference to more structured and organized approaches to jamming and even spoofing.

We're predicting a game of cat and mouse where these cyber attacks and interference threats will continually evolve to try and stay one step ahead of the protections in place. In our view, this will call for increasingly clever and proactive threat-detection techniques in navigation systems, in addition to precise, reliable test solutions to verify them.

Spirent's test solutions address these growing demands by providing not only multi-GNSS signal simulators, but also inertial and interference simulators, anti-jamming test solutions, and record and replay of actual observed interference and even communications port vulnerability testing.

In our view, the diversity of critical applications will increase, emphasizing the need for a precise approach to test planning, execution and analysis. Robust PNT is an achievable vision, and we are excited for the future.

JOHN POTTLE is marketing director for Spirent Communications plc.

NEAL FEDORA is director of engineering for Spirent Federal Systems Inc.

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The 2015 ENC conference will be hosted by the Institut Français de Navigation (IFN) and TOPOS Aquitaine with the support of CNES and THALES and held from April 8 through 10 at Centre de Congrès Cité mondiale in Bordeaux, France.

Five good reasons to be there:

- Organized under the auspices of the European Group of Institutes of Navigation (EUGIN)
- Four keynote speakers and panel sessions with European Commission, ESA, Eurocae, GSA, DLR, CNES, DGAC key representatives and a wide participation of Industry
  1) The impact of GNSS on the economic sector - how to promote and support the expansion of a downstream European sector in the field of navigation
  2) GNSS for aeronautical applications; from GPS to Multiconstellation with Galileo
  3) GNSS resilience and robustness for Terrestrial and Naval applications (ADAS, Rail, Timing,...)
  4) Alternative GNSS positioning systems

Registration is currently possible via the conference website.

ABOUT BORDEAUX

Bordeaux is the world's capital of wine and has been registered as a UNESCO World Heritage Site since 2007. The city is an 18th century architectural gem and counts up to 350 historic monuments.

Bordeaux and the Aquitaine region are long-time and sustainable investors in the aerospace, space and defence sector industry and are the co-host of "Aerospace Valley", the international cluster for competitiveness. Aquitaine is a leading region for per capital R&D investment and develops the potential for innovation of start-ups in the avionics, drones, space, composite and photonics sectors. Bordeaux is also welcoming home to the the largest inertial confinement fusion experiment in Europe called Laser Mégajoule.

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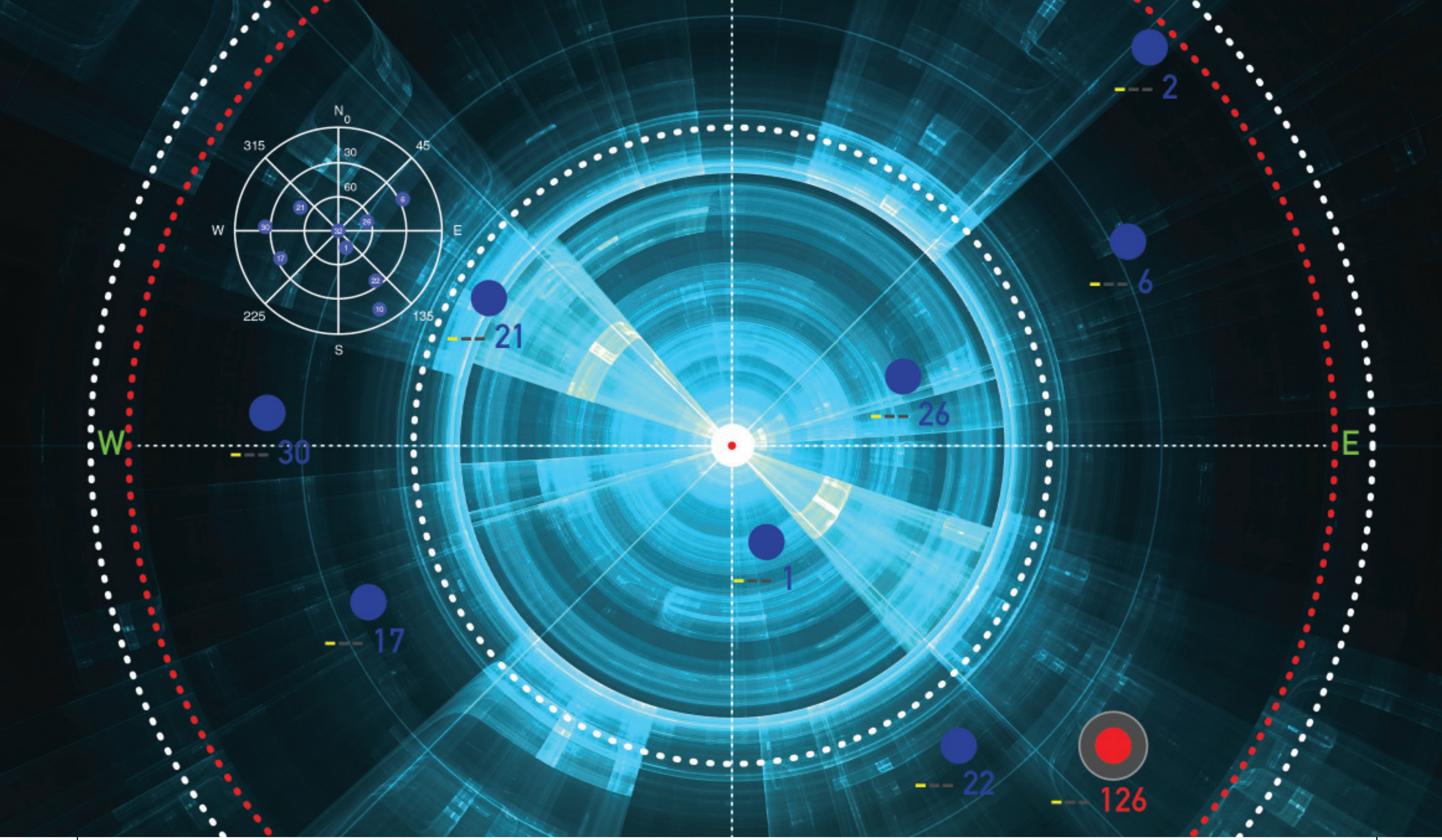


Antenna Array and Receiver Testing

With a Multi-RF Output GNSS Simulator

This article discusses the GALANT adaptively steered antenna array and receiver, demonstrating the test scenarios generated with the GNSS simulator. Exemplary results of different static and dynamic test scenarios are presented, validating the attitude determination capabilities as well as the interference detection and mitigation capabilities.

Thorsten Lück, Günter Heinrichs, *IFEN GmbH*, and Achim Hornbostel, *German Aerospace Center*

The vulnerability of GNSS to radio frequency interference and spoofing has become more and more of a concern for navigation applications requiring a high level of accuracy and reliability, for example, safety of life applications in aviation, railway, and maritime environments.In addition to pure power jamming with continuous wave (CW), noise or chirp signals, cases of intentional or unintentional spoofing with wrong GNSS signals have also been reported.

Hardware simulations with GNSS constellation signal generators enable the investigation of the impact of radio interference and spoofing on GNSS receivers in a systematic, parameterized and repeatable way. The behavior of different receivers and receiver algorithms for detection and mitigation can be analyzed in dependence on interference power, distance of spoofers, and other parameters. This article gives examples of realistic and advanced simulation scenarios, set up for simulation of several user antennas simultaneously.

The professional-grade high-end satellite navigation testing and R&D device used here is powerful, easy to use, and fully capable of multi-constellation / multi-frequency GNSS simulations for safety-of-life, spatial and professional applications. It provides all L-band frequencies for GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS and beyond in one box simultaneously. It avoids the extra complexity and cost of using additional signal generators or intricate architectures involving several hardware boxes, and offers full control of scenario generation. A multi-RF capable version provides up to four independent RF outputs and a master RF output that combines the RF signal of each of the up to four individual RF outputs.

Each individual RF output is connected to one or more "Merlin" modules (the core signal generator module for one single carrier) allowing simulation of up to 12 satellites per module. Because of the flexible design of the Merlin module, each one can be configured to any of the supported L-band frequencies.

As one chassis supports up to nine individual Merlin

VB-RTK

BREAKING NEWS

Get on the Grid with VB-RTK. For over a decade American surveyors have been using the National Geodetic Survey's Online Positioning User Service. Surveyors employing RTK have been a significant share of the user segment of OPUS.

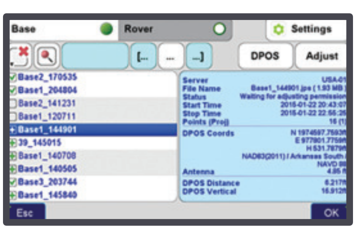
A significant share of OPUS users are surveyors using RTK. Often a surveyor will set up his base on a new, unknown position and allow an autonomous (or standalone) position to be used for the base coordinates. While he is performing his RTK work with fixed vectors between his base and rover, he stores data at the base to be submitted at a later time to OPUS. Once he is finished with his work, he downloads this file to his computer, converts the file if necessary, and submits it to OPUS. He then receives an email response back with a precisely determined coordinate for his base station. He then must take this coordinate, relate the coordinate to his project coordinate system, and then translate the work from the autonomous (or standalone) position he used in the field to this new coordinate. This procedure can produce excellent results and anchors the survey to the NSRS. The down side to this is that there are several steps that must be carefully observed and each of these error prone steps costs time.

With J-Field data collection software, JAVAD has been automating many tasks that surveyors have been doing for years, making the tasks more efficient and reducing sources of potential error. One example, **"Verify RTK with V6 Resets"**, is being recognized by surveyors across the country as the most accurate and efficient way to confidently determine RTK positions. Rather than taking a shot, manually resetting (or dumping) the receiver and taking a second shot for comparison, Verify RTK does this automatically with a user defined number of reset iterations.

JAVAD has continued this automation philosophy by dramatically simplifying the process of translating a survey from an autonomous base position to precise geodetic coordinates with **VB-RTK (Verify Base – RTK)**. Using the JAVAD GNSS, Data Processing Online Service (DPOS), which is powered by the proven JAVAD GNSS Justin processing engine. **This multi-level process is done in J-Filed completely automatically.**

Once an RTK session has been completed, the user returns to his JAVAD base receiver and presses "Stop Base" on the TRIUMPH-LS. **At this point, the raw data file that has been recording at the base during the session, is wirelessly downloaded from the base to the TRIUMPH-LS. When the download is complete, the user returns to his office and connects the TRIUMPH-LS to the internet.**

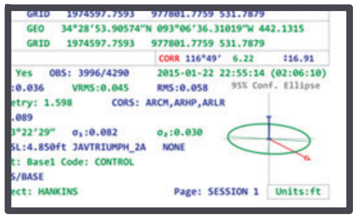
When internet connection is made, the file is automatically transmitted to one of the JAVAD GNSS servers for post processing. Once data and ephemerides are available for the session, **DPOS** processes the file and returns results to the waiting TRIUMPH-LS. This all takes within minutes.



Once results are returned, the new coordinates for the base are shown related to your coordinate system (including localization systems).

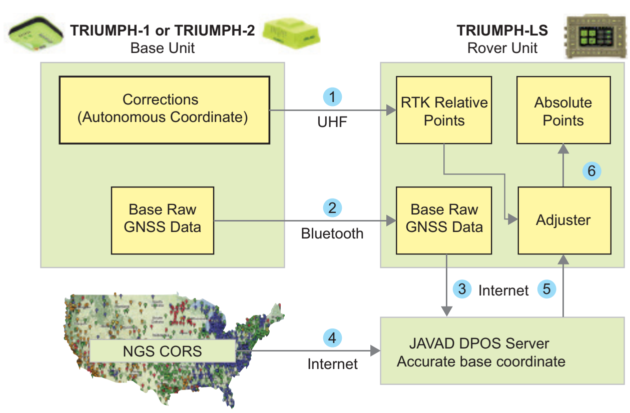
The horizontal and vertical differences between the base coordinates used and the DPOS determined coordinates are shown. **This provides for an instant check of the base coordinates and instrument height** if the base were set up on a known position.

All rover points associated with that base session translate automatically in seconds. Only those rover points associated with that base session translate.

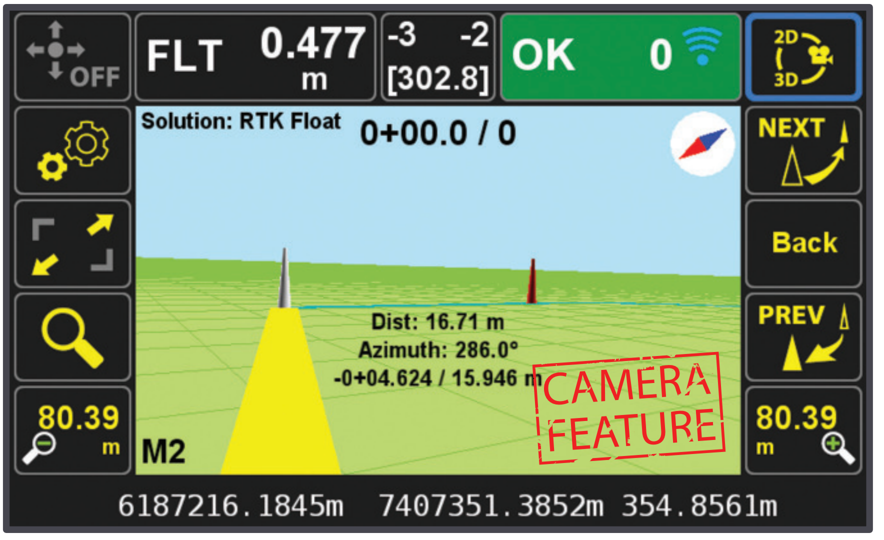


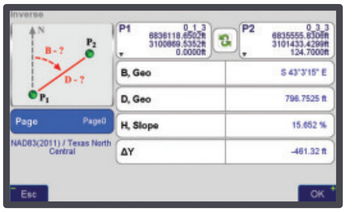
If the user is not satisfied with the results of the DPOS solution and wants to revert back to the original RTK positions, he simply clicks **"Undo"**.This process is immune to base instrument height errors because the internal vectors between base to rover are related to the antenna, not the ground point. So, an accidental entry for the base height of 543' instead of 5.43' can be resolved by VB-RTK.

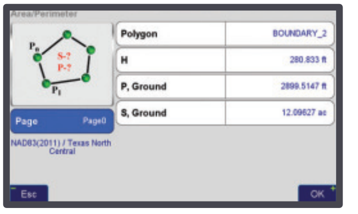
In addition to the advantages of having your RTK base station near your work area, which gives you much more accurate and faster fixes, especially in difficult areas, and saving you the RTN chargest; perhaps most important of all, your work is now precisely related to one of the most accurate geodetic control networks in history – the NGS CORS. Every rover point is only two vectors removed from the CORS (CORS to base, base to rover). This means that you can return again someday to find your monuments easily and accurately. This makes your records incredibly more valuable to both you and future surveyors. J-Field also has the unique ability to load and view every point you have ever surveyed from all the projects in its system. By combining this feature with a **distance filter** in its advanced set of filters, you can easily view all the points you have previously surveyed within a given distance of a point in your current project. Having an easily accessible record of nearby georeferenced coordinates is very beneficial as you may have previously located monuments in past surveys that are beneficial in your current project. J-Field allows you to easily copy these selected points into your current project, eliminating the need for you to resurvey them. All of this is available automatically on the world's most advanced RTK rover – **the TRIUMPH-LS**.

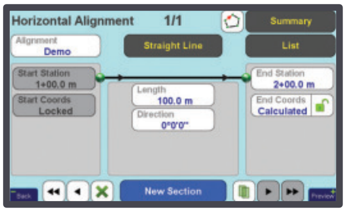


You do 1, the rest is automatic









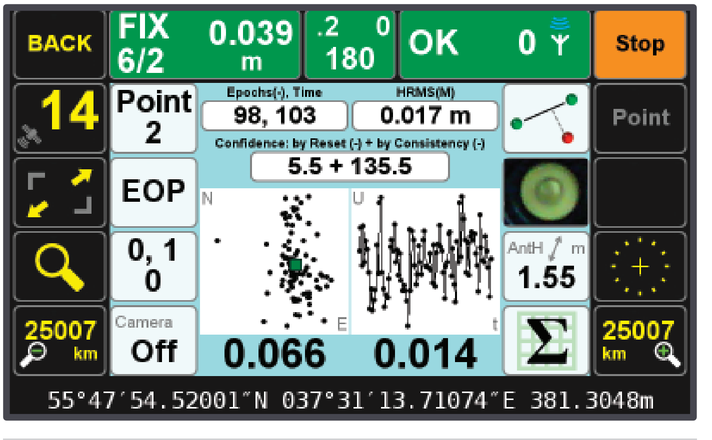
Store and Stake

Introducing GUIDE data collection in the TRIUMPH-LS. Visual Stake-out, navigation, six parallel RTK engines, over 3,000 coordinate conversions, advanced CoGo features, rich attribute tagging on a high resolution, large, bright 800x480 pixel display. Versatile attribute tagging, feature coding and automatic photo and voice documentation.
The TRIUMPH-LS automatically updates all firmware when connected to a Wi-Fi internet connection.

View and Document your level

The downward camera of TRIUMPH-LS scans and finds the liquid bubble level mounted on the pole. Then focuses on the circular bubble automatically and shows its image on one of the eight white buttons of the Action Screen. You can:

- View the liquid bubble level on the screen.
- Document survey details including the leveling by taking automatic screen shots of the Action Screen, as shown here.
- Calibrate the electronic level of TRIUMPH-LS with the liquid bubble level for use in Lift and Tilt and automatic tilt corrections.



All these camera features are possible only in TRIUMPH-LS where camera, and GNSS antenna are co-located and all other modules integrated.

OMEGA

Rugged GNSS Unit

OMEGA is the most advanced GNSS receiver. It does not include integrated antenna and controller. It is suited for applications like **machine control** and in **marine** and **avionics** applications.

Adding GrAnt and Victor-LS makes a complete RTK system.

It is well suited for **monitoring and network stations**.

OMEGA + Victor-LS + GrAnt

TRE-3

The state-of-the-art in GNSS technology...

And this is why:

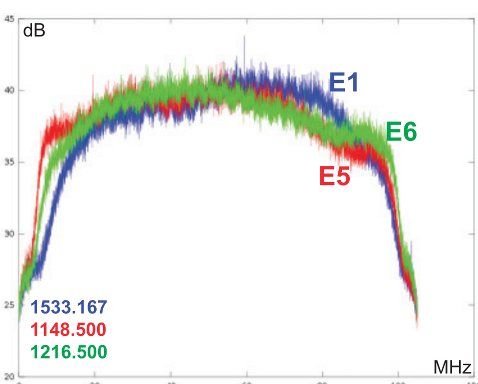
- **Three** ultra wide-band (**100 MHz**) fast sampling and processing, programmable digital filters and superior dynamic range. After **12-bit** digital conversion, **nine** separate digital filters are perfectly shaped for each of the nine GPS L1/Galileo E1, GPS L2, GPS L5/ Galileo E5A, GLONASS L1, GLONASS L2, Galileo E5B/BeiDou B2/GLONASS L3, Galileo altBoc, Galileo E6/BeiDouB3/QZSS **LEX**, and BeiDou B1 bands.

- Each band consists of a combination of a digital Cascaded Integrator-Comb (**CIC**) filter and a digital Finite Impulse Response (**FIR**) filter (up to **60-th** order) where signal selection is performed.

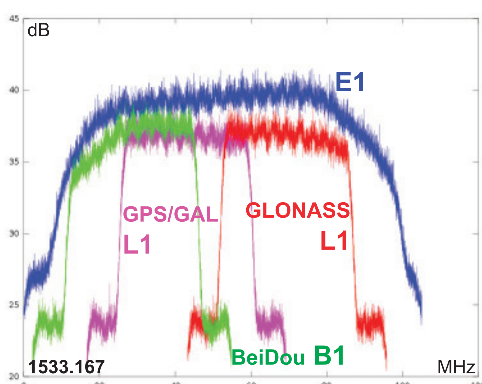
- Two types of digital in-band anti-jamming filters (automatic **80-th** order and "user selectable" **256-th** order).

- We assign multiple channels to acquire and track each satellite signal. For example we can assign **20** channels to acquire the GPS L1 signal, each spaced one millisecond apart. We also assign up to **5 channels** to track each signal, each with different filter parameters and tracking strategies. This supports acquiring and tracking **weaker** signals in difficult conditions, especially under trees and canopy. People wonder why we need **864** channels! We put them to good use. Others use one channel per satellite signal. Several patents are pending (Patents and Pendings).

- **80 dB** out-of-band interference rejections: high dynamic range of wide RF bands and highly rectangular digital filters make the receiver much more resistant to out-of-band **jamming**.



Noise spectrum of three wide RF bands (seen from DSP) with 3 level signal quantization



Noise spectrums of GNSS Bands which were cut from E1 wide RF band by corresponding digital filter

- **High-speed** high-dynamic automatic gain control (AGC) to respond to interferences and signal variations.

- Programmable filter **width** (by commands).

- Highly stable digital filters (band characteristics do **not change** with age, input voltages, or temperature).

- Improved **GLONASS** inter-channel bias performance (due to our flat digital filter shape).

- Excellent new **multipath** rejection technique, the best ever.

- 60-MHZ-wide Galileo **altBoc** band unleashes the full benefit of this signal. Its excellent multipath resistance is improved even further with our new multipath reduction technique.

- **864** GNSS channels allow tracking all current and future satellite signals.

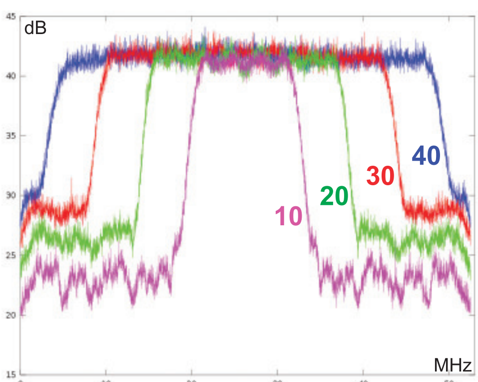
- Three wide band RF sections allow monitoring **spectrums** and interferences in three 100-MHz-wide bands.

- TRE-3 is the only receiver in the market that can track AND DECODE the QZSS **LEX signal messages**.

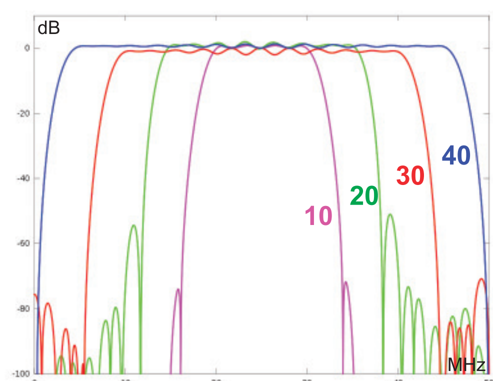
- Excellent features for **time transfer** applications: In time sources where the zero crossing of the input frequency defines the exact moment of the time second, we monitor **zero crossings** and accurately define the moment of the time second. External time interval measurement unit is not required to measure zero crossing and 1-PPS offset.

- Embedded **calibrator** measures phase and code delays of each of these nine bands in timing applications. External calibration is not required.

TRE-3 is form, pin-out, and command compatible with the TRE-G3T.It uses **7-Watts** of power, compared to 4-Watts of the TRE-G3T.



Noise spectrums of GPS L1/Galileo E1 band with different digital filter band width (set by command)



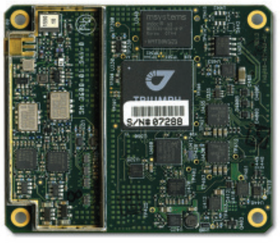
Amplitude response of combination of digital CIC and FIR filters, computed on Matlab. Real out-band attenuation

and more...

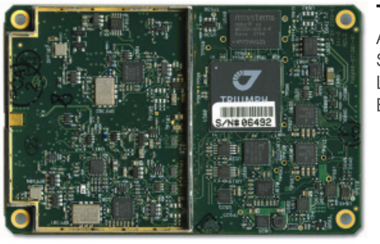
Available in all boards:
RAIM; On-Board Power supply; Reduced MinPad; RS232(A) 460 kbaud; USB; Fast acquisition channels; Advanced Multipath Reduction; 1PPS; Event; IRIG A/B; Up to 100 Hz update rate for real time position and raw data

TRH-G2
All-in-view
GPS L1; SBAS L1; Galileo E1;
BeiDou B1; QZSS L1;
UART(A) 460 kbaud *

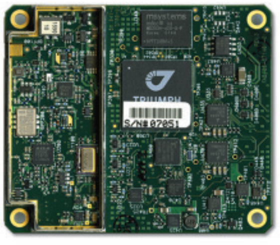
TR-G2
All-in-view
GPS L1; SBAS L1;
Galileo E1; BeiDou B1;
QZSS L1



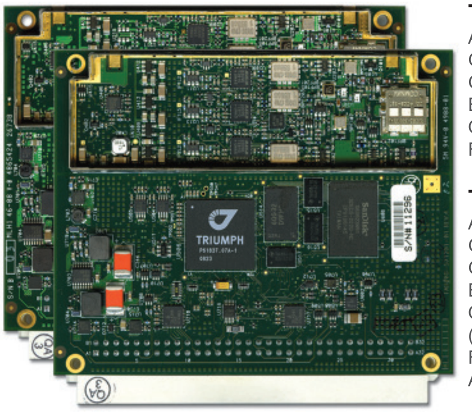
TR-G3
All-in-view
GPS L1; SBAS L1;
GLONASS L1;
Galileo E1;
BeiDou B1;
QZSS L1



TR-G3T
All-in-view GPS L1/L2/L5;
SBAS L1/L5; GLONASS
L1/L2; Galileo E1/E5A;
BeiDou B1; QZSS L1

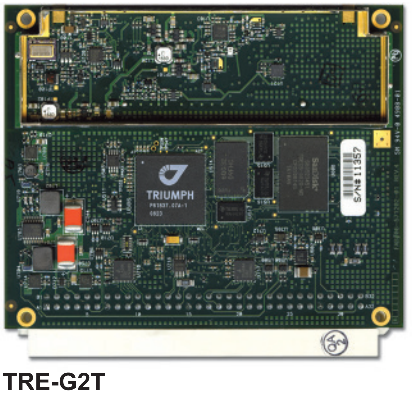


TR-G2T
All-in-view
GPS L1/L2/L5;
SBAS L1/L5;
Galileo E1/E5A;
BeiDou B1;
QZSS L1

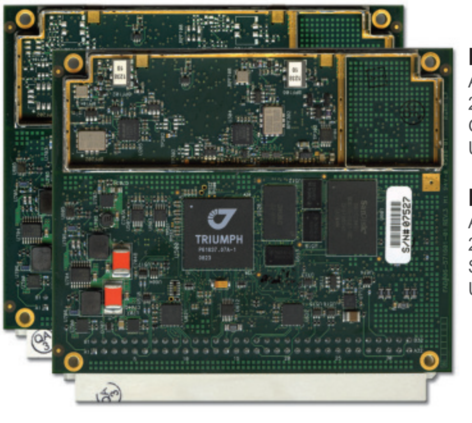


TRE-G3T
All-in-view**
GPS L1/L2/L5; SBAS L1/L5;
GLONASS L1/L2/L3, Galileo E1/
E5A/E5B/AltBoc; BeiDou B1/B2;
QZSS L1/L2/L5; Ethernet;
Frequency Input/Output

TRE-G3TAJT
All-in-view**
GPS L1/L2/L5; SBAS L1/L5;
GLONASS L1/L2/L3; Galileo E1/
E5A/E5B/AltBoc; BeiDou B1/B2;
QZSS L1/L2/L5; Ethernet
(also support for IEEE 1588);
Frequency Input/Output;
Anti-jamming



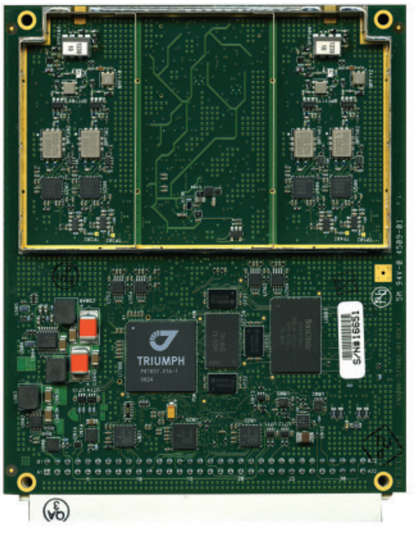
TRE-G2T
All-in-view GPS L1/L2/L5; SBAS L1/L5; Galileo E1/E5A; BeiDou B1; QZSS L1/L2/L5; Ethernet

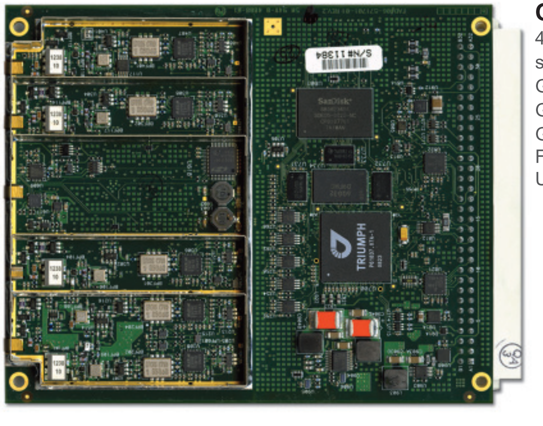


Duo-G2
All-in-view
2 groups of GPS L1; SBAS L1;
Galileo E1; Ethernet;
Up to 50 Hz Heading rate

Duo-G2D
All-in-view
2 groups of GPS L1/L2;
SBAS L1; Galileo E1; Ethernet;
Up to 50 HzHeading rate

Duo-G3D
All-in-view 2 groups of GPS L1/L2; SBAS L1;
GLONASS L1/L2, Galileo E1; Ethernet;
Up to 50 Hz Heading rate



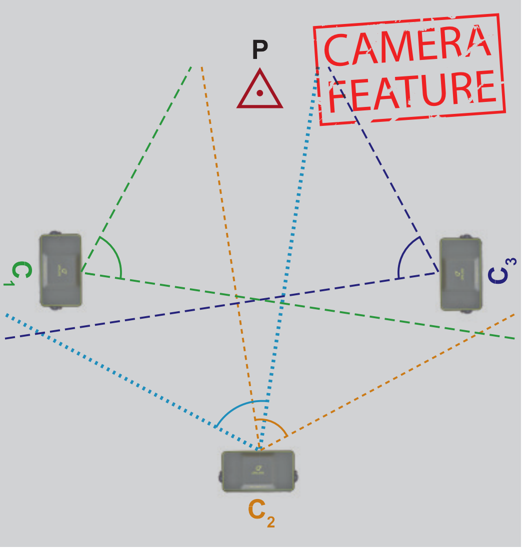


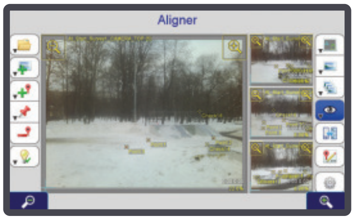
Quattro-G3D
4 groups (up to 12 satellites per group) of GPS L1/L2; SBAS L1; GLONASS L1/L2; Galileo E1; Ethernet; Frequency Input/Output; Up to 20 Hz Attitude rate

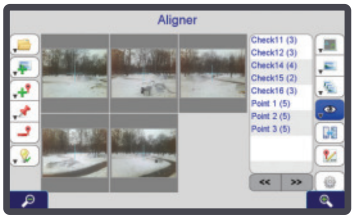
** Not available in this board: Reduced MinPad; RS232(A) 460 kbaud; USB; 1PPS; Event; IRIG A/B*
*** May be not applicable for simultanious tracking of Galileo and BeiDou*

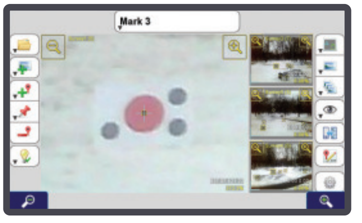
Offset Survey with built in camera

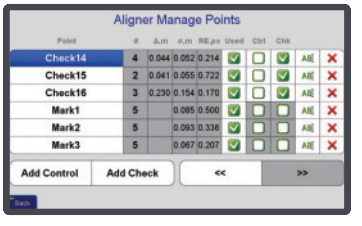
You can survey points with internal TRIUMPH-LS camera with accuracy of about 2 cm. Take pictures from at least three points. Leave a flag on points that you take pictures from, otherwise accuracy will be about 10 cm.

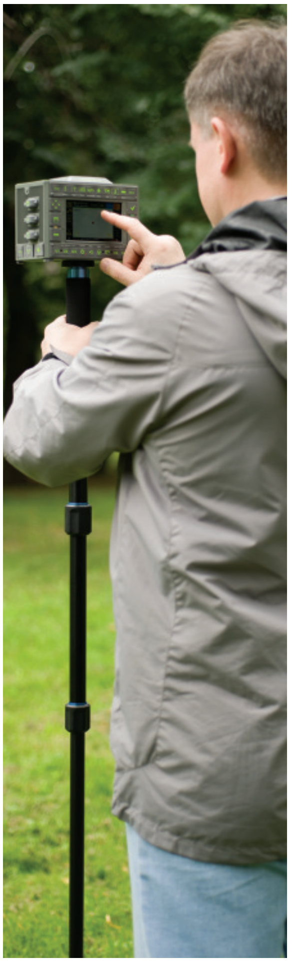










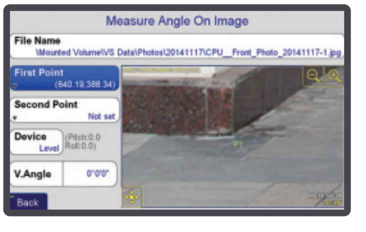


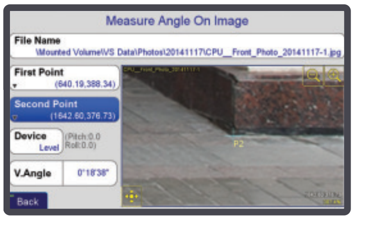
Visual Angle Measurement with Triumph LS

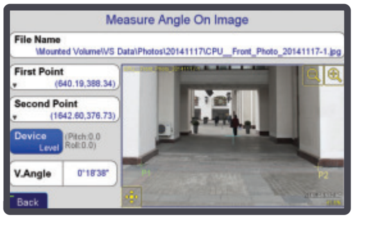
The new Visual Angle Measurement function of the TRIUMPH-LS allows measuring angles between points by using photos taken by the TRIUMPH-LS camera and use in CoGo tasks with the Accuracy of about 10 angular minutes.

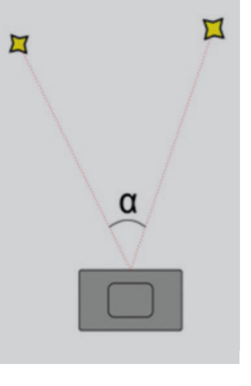
To measure an angle:

- just take an image containing both objects of interest and open it in the Measure Angle screen
- select first and second point (using zoom to focus on necessary features)
- The angle between points is immediately displayed on the screen.



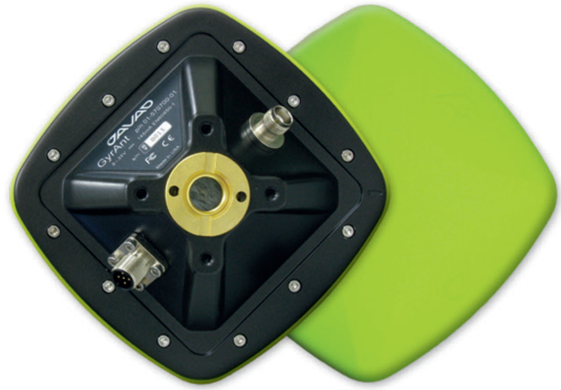






High performance
Antennas

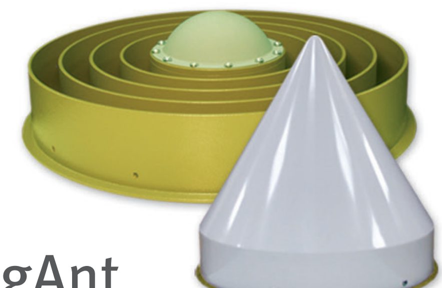
TriAnt



AirAnt

RingAnt

GrAnt



A variety of Radio Modems. Bluetooth and USB in all JAVAD radios
See details at **www.javad.com**

JLink 3G

JLink 3G BAT

**HPT435BT/HPT135BT/
HPT225BT**

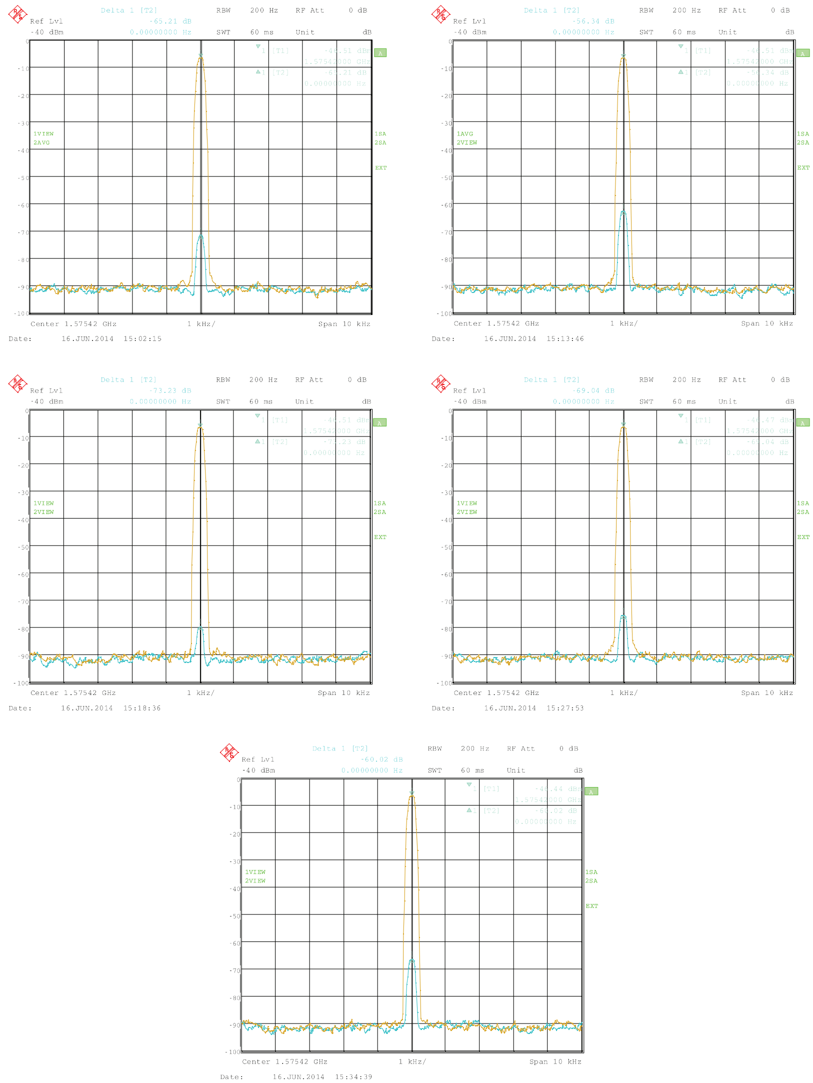
modules, different Multi-RF combinations are feasible:

- two RF outputs with up to four modules each
- three RF outputs with up to three modules each
- four RF outputs with up to two modules each.

With these configurations, the user can simulate different static or dynamic receivers or even one receiver with multiple antennas, covering such challenging scenarios as ground networks, formation flying or use of beam-forming antennas.

As the user is free to assign each individual module to a dedicated simulated antenna, the user could also employ up to nine modules to simulate nine different carrier signals for one single antenna using the master RF output, thus simulating the complete frequency spectrum for all current available GNSS systems in one single simulation.

All modules are calibrated to garantee a carrier phase coherency of better than ±0.5°. **FIGURE 1** shows the output at the RF master of two modules assigned to the same carrier but with a phase offset of 180°.Theoretically the resulting signal should be zero because of the destructive interference. In practice, a small residual signal remains because of component tolerance, small amplitude differences and other influences. Nevertheless the best cancellation can be seen at this point.



▲ **FIGURE 1** Carrier-phase alignment of the high-end simulator with six modules compared to the first module.

The phase accuracy can now simply be estimated from the measured power level of the residual signal:

$$s(t) = \sin(2\omega t) + \sin(2\omega t + \varphi) \quad (1)$$

$$= 2\sin\left(\frac{2\omega t + \varphi}{2}\right)\cos\left(-\frac{\varphi}{2}\right) \quad (2)$$

$$= 2\sin\left(2\omega t + \frac{\varphi}{2}\right)\cos\left(\frac{\varphi}{2}\right)$$

$$= A\sin\left(2\omega t + \frac{\varphi}{2}\right)$$

with

$$A = 2\cos\left(\frac{\varphi}{2}\right)$$

This means that the sum of two sine waves with the same frequency gives another sine wave. It has again the same frequency, but a phase offset and its amplitude is changed by the factor A. The factor A does affect the power level. If φ is 180° then A is 0, which means complete cancellation.

So A shows the power of the resulting signal relative to the single sine wave. It can also be transformed to dB:

$$A_{dBc} = 20\log_{10}(A) \quad (3)$$

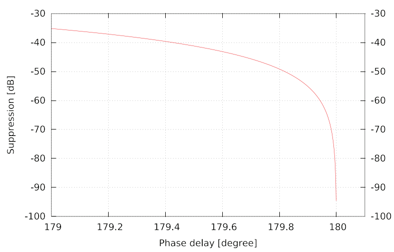
$$= 20\log_{10}\left(2\cos\left(\frac{\varphi}{2}\right)\right)$$

FIGURE 2 shows the carrier suppression as a function of carrier phase offset with a pole at 180°.

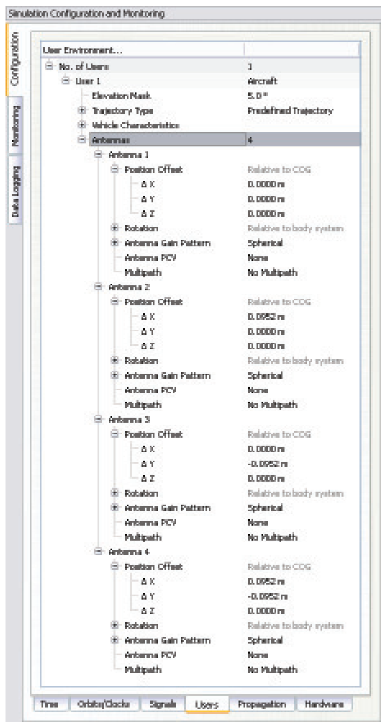
The factory calibration aligns the modules to a maximum of 0.5° misalignment. The measured suppresion therefore shall be better than 41.18 dBc. In practice, the residual signal is also caused by other influences, so that the actual phase alignment can be expected to be much better.

With four RF outputs, the received signal of a four element antenna can be configured very easily. **FIGURE 3** shows the dialog to configure a four-element antenna with the geometry shown in **FIGURE 4**. Note that the antenna elements are configured in the body-fixed system with the *x*-axis to front and the *y*-axis to the right (inline with a north-east-down, NED, system when facing to north), while the geometry shown in Figure 4 follows an east-north-up (ENU) convention.

The following sections give an overview of multi-antenna systems and discuss results from a measurement campaign of the German Aerospace Center (DLR) utilizing the simulator and the DLR GALileo ANTenna array (GALANT) four-element multi-antenna receiver.



▲ **FIGURE 2** Carrier suppresion as a function of phase delay.



▲ **FIGURE 3** Configuration of individual antennas per receiver.

Multi-Antenna Receivers

Multi-antenna receivers utilize an antenna array with a number of antenna elements. The signals of each antenna element are mixed down and converted from analog to digital for baseband processing. In the baseband, the signals received by the different antenna elements are multiplied with complex weighting factors and summed. The weighting factors are chosen in such a way that the received signals from each antenna element cancel out into the direction of the interferers (nulling) and additionally, for advanced digital beamforming, such that the gain is increased into the direction of the satellites by forming of individual beams to each satellite. Because all these methods work with carrier phases, it is important that in the simulation setup, the signals contain the correct carrier phases at the RF-outputs of the simulator corresponding to the user satellite and user-interferer geometry, and the position and attitude of the simulated array antenna.

FIGURE 5 presents the geometry of a rectangular antenna array with 2x2 elements and a signal *s(t)* impinging from direction (ϕ, θ).

The spacings of the elements *dx*, *dy* are typically half a wavelength, but can also be less. The range difference for antenna element *i* relative to the reference element in the center of the coordinate system depends on the incident direction (ϕ, θ) and the position ($m=0,1$, $n=0,1$) of the element within the array:

$$\Delta r_i = md_x \sin\theta \cos\varphi + nd_y \sin\theta \sin\varphi \qquad (4)$$

The corresponding carrier phase shift is:

$$\Delta\Phi_i(\theta, \varphi) = -\frac{2\pi}{\lambda}\Delta r_i \qquad (5)$$

For CRPA and adaptive beam forming applications, the differential code delays may be neglected if they are small compared to the code chip length. However, it is essential that the carrier phase differences are precisely simulated, because they contain the information about the incident direction of the signal and are the basis for the array processing in the receiver. For instance, the receiver can estimate the directions of arrival of the incident signals from these carrier phase differences.

Now we consider a 2x2 array antenna. It can be simulated with the simulator with four RF outputs, where each output corresponds to one antenna element. In the simulator control software, a user with four antennas is set up, where the position of each antenna element is defined as an antenna position offset relative to the user position. In this approach, both differential code and carrier delays due to the simulated array geometry are taken into account, because the code and carrier pseudoranges are computed by the simulator for the position of each antenna element. However, the RF hardware channels of the receiver front-end may have differential delays against each other, which may even vary with time. If the direction of the satellites and interferers shall be estimated correctly by the receiver algorithms, a calibration signal is required to measure and compensate these differential hardware delays.

For the real antenna system, a binary phase-shift keying (BPSK) signal with zero delay for each antenna channel is generated by the array receiver and fed into the antenna calibration port. For the simulation, this calibration signal must also be generated by the constellation simulator.

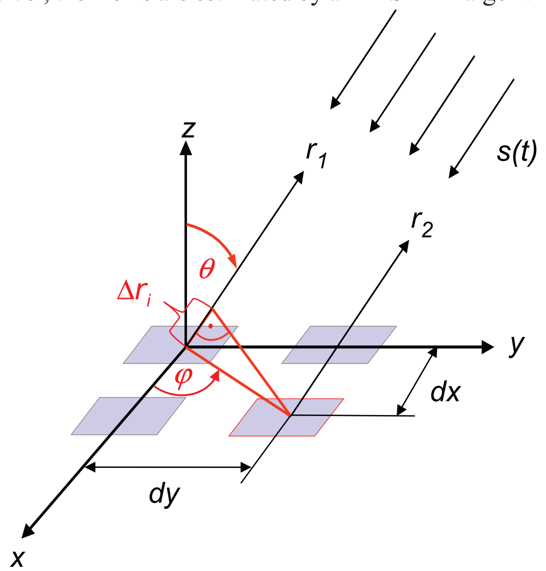
In a simple way, a satellite in the zenith of the user antenna can be simulated, which has the same distance and delay to all antenna elements. Unfortunately, this simple solution includes some limitations to the simulated position and attitude of the user, because the user position must be at the Equator (if a "real" satellite is simulated in form of a geostationary satellite) and the antenna must not be tilted.

With a small customization of the simulator software, these limitations could be overcome. **FIGURE 6** shows how to set up the generation of a reference signal. This reference signal can either be simulated as a transmitter directly above the user position, which follows the user position and thus allows also simulations offside the Equator, or simulated as a zero-range signal on all RF outputs, neglecting any geometry, which is the preferred method. The latter one is more or less identical to the reference/calibration signal generated by the receiver itself.

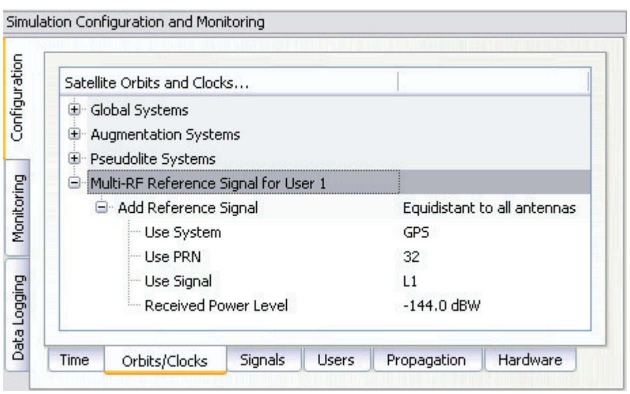
The power level of this signal is held constant and is not affected by any propagation delay or attenuation simulated by the control center.

Attitude Determination

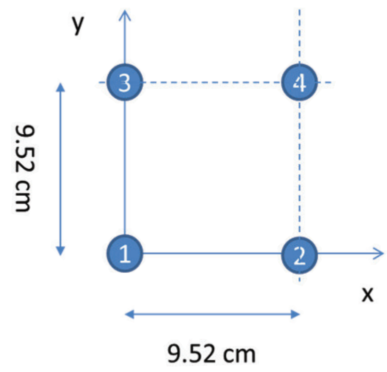
According to Figure 5, the phase difference measured between antenna elements is a function of the direction of arrival (DoA). Thus, the DoAs of the incident signals can be estimated from the phase differences. In the GALANT receiver, the DoAs are estimated by an EPSPRIT algorithm



▲ **FIGURE 5** Parallel wavefront impinging on a rectangular array with 2x2 elements.



▲ **FIGURE 6** Configuration of a modulated reference signal.



▲ **FIGURE 4** Geometry of the GALANT four-element phased-array antenna (view from top).

after correlation of the signals. Compared with the (known) positions of the GNSS satellites, this allows the estimation of the antenna array attitude. **FIGURE 7** shows the sky-plot of simulated satellites as seen at receiver location (simulated on the right; reconstructed by the receiver from the decoded almanac in the middle and the DoA on the left). By comparison of the estimated DoAs of all satellites and the skyplot from the almanac, the attitude of the antenna is estimated (left). In addition, the attitude angles simulated by the simulator is given (right).

Simulation of Interference

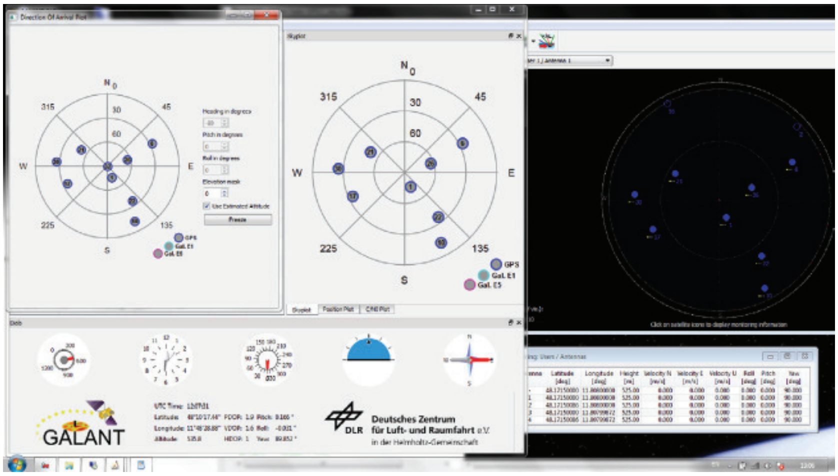
It is possible to simulate some simple types of interference. Possible interference scenarios are:

Wideband Noise. By increasing the power of a single satellite of the same or another GNSS constellation, a wideband pseudo-noise signal can be generated. Using a geostationary satellite also enables simulating an interference source at low elevations and constant position. Use of power-level files also allow generation of scenarios with intermittent interference (switching on and off the interference) with switching rates up to 5 Hz.

CW or Multi-Carrier IF. By disabling the spreading code and navigation message, a CW signal can be generated. The simulator also allows configuration of subcarrier modulations. Without spreading code (or to be precise with a spreading code of constant zero) the generated signal will consist of two carriers symmetrically around the original signal carrier (for example, configuring a BOC(1,1) signal will create two CW signals at 1.57542 GHz ± 1.023 MHz, thus producing “ideal” interferer for the Galileo E1 OS signal.)

Depending on the number of Merlin modules per RF output, interference to signal ratios up to 80 dB could be realized, limited by a dynamic range of 40 dB within one module and additional 40 dB range between two modules. However, the maximum power level of one individual signal is currently limited to -90 dBm. If only one channel per module is used, the maximum power level of this single signal can be increased by another 18 dB (for example, by using one module solely for interference generation and another module for GNSS simulation).

FIGURE 8 shows the simulated geometry for an interference scenario based on wideband noise generated by a



▲ **FIGURE 7** Simulating and estimating attitude with a multi-element antenna.

geostationary satellite, producing –90 dBm signal power at the receiver front end. The interference source is very near to the direction of PRN 22 with a jammer power of –90 dBm, resulting in a jammer to signal ratio of J/S = 25 dB.

FIGURE 9 shows the two-dimensional antenna pattern as a result of the beam-forming before and after switching on the interferer. The mitigation algorithm tries to minimize gain into the direction of the interferer. As this also decreases gain into the direction of the intended satellite, the C/N_0 drops by approximately 10 dB for PRN 22, because its main beam is shifted away from the interference direction. For satellites in other directions, the decrease in C/N_0 is less: compare Figure 9 with **FIGURE 10**. However, the receiver still keeps tracking the satellite. After switching of beamforming, the signal is lost.

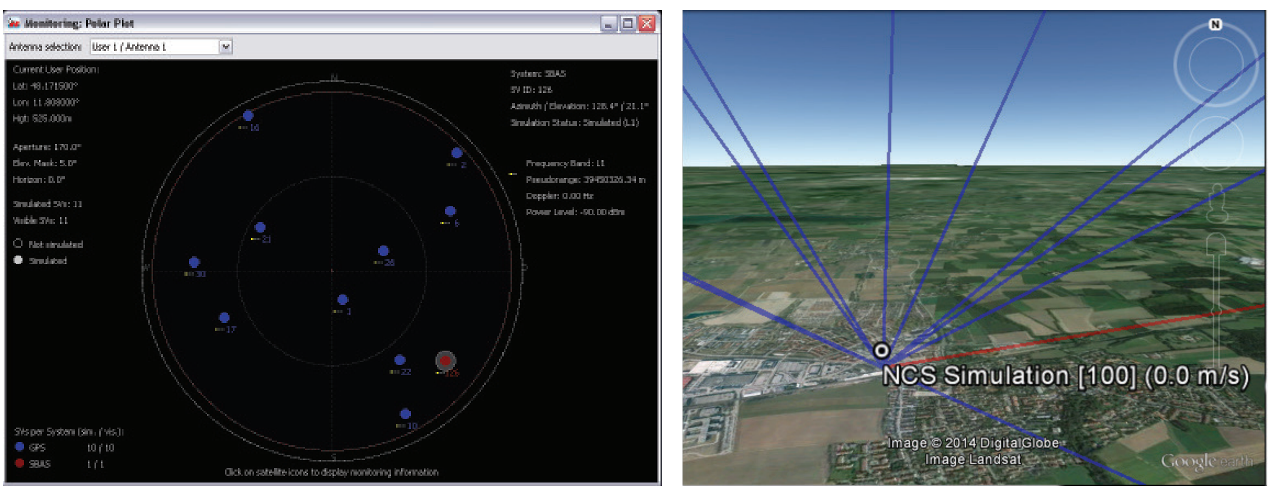
Simulation of Spoofing

The simulation of a spoofing signal requires twice the resources as the real-world scenario, as every "real" LoS-signal must also be generated for the spoofing source. A simulation of an intentional spoofer who aims to spoof a dedicated position in this context is, however, very similiar to the simulation of a repeater ([un-] intentional interferer) device:

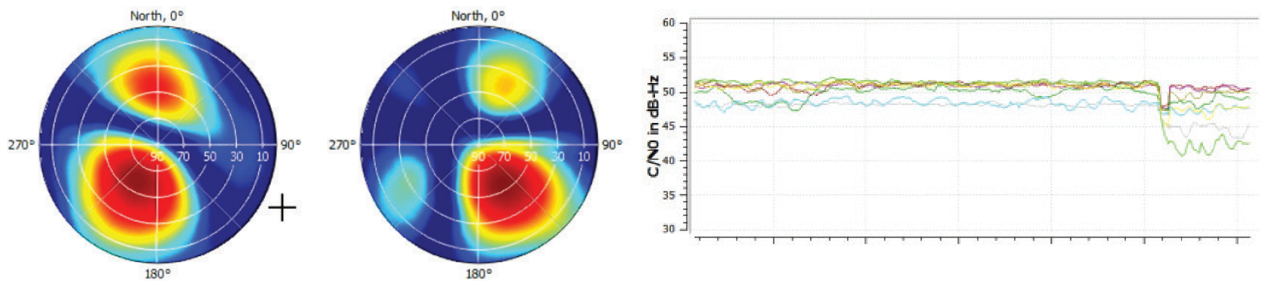
The repeater (re-)transmits the RF signal received at its receiver position. A receiver tracking this signal will generate the position of the repeater location but will observe an additional local clock error defined by the processing time within the repeater and the travel time between repeater and receiver position. A correct simulation for a multi-antenna receiver therefore has to superpose the code and carrier range as observed at the repeater location (considering geometric range between the transmit antenna of the repeater and the individual antenna elements) with the code and carrier ranges at the receiver location.

Instead of the location of the repeater P2, however, any intended location Px could be used to simulate an intelligent spoofer attack (**FIGURE 11**).

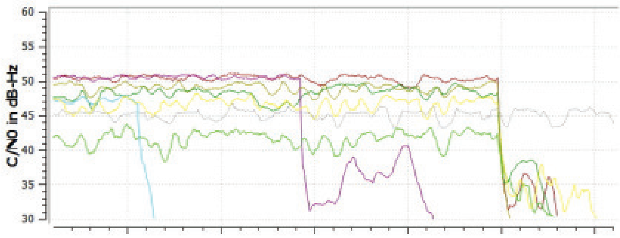
The simulator can generate such scenarios by configuring the position of the (re-)transmitting antenna and the intended position (for example, the position of the repeater). By calculating the difference between the real receiver position and the position of the transmitting antenna, the additional delay and free-space loss can be taken into account. The user may also configure the gain of the transmit antenna and the processing time within the repeater. Currently, this setup does only support one "user" antenna to be simulated. However, this feature combined with multi-antenna support will enable the simulator to simulate repeater or intelligent spoofer attacks in the future (**FIGURE 12**). To distinguish the "real" signal from the "repeated" signal, the "repeated" signal



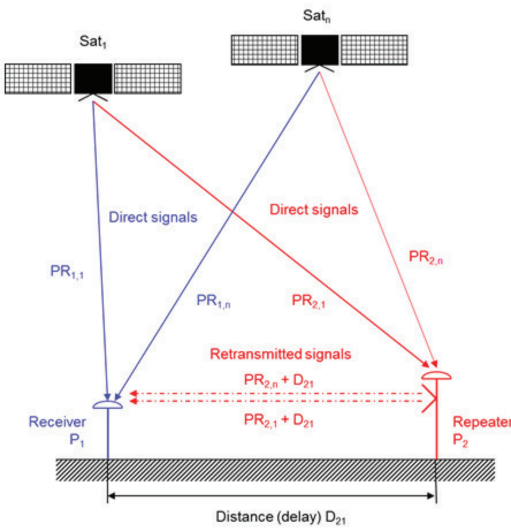
▲ **FIGURE 8** Geometry for the wideband noise interference scenario.



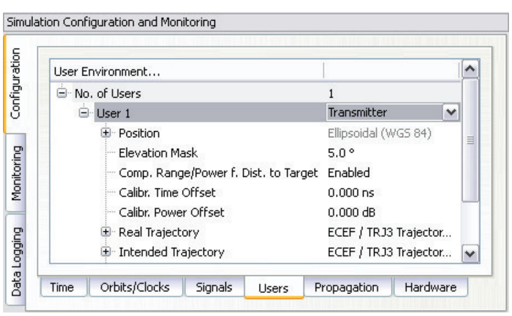
▲ **FIGURE 9** Beamforming for PRN 22 (light green line in lower plot) to mitigate for interference.



▲ **FIGURE 10** Tracking is lost after switching off beamforming for individual channels (light blue, purple) and all channels (at the end of the plot).



▲ **FIGURE 11** Geometry of repeater/spoofer and GNSS receiver.



▲ **FIGURE 12** Simulator's capability to simulate a repeater.

could be tagged as a multipath signal. This approach would allow simulation of the complete environment of "real" and "repeated" GNSS signals in one single simulator.

Manufacturers

The simulator producing the results described here is the NavX-NCS from **IFEN GmbH** (*www.ifen.com*).The simulator is valuable laboratory equipment for testing not only standard or high-end single-antenna GNSS receivers, but also offers additional benefit for multi-antenna GNSS receivers like the DLR GALANT controlled reception pattern antenna system.

The GNSS constellation simulator offers up to four phase-coherent RF outputs, allowing the simulation of four antenna elements with two carrier frequencies, each utilizing one single chassis being 19 inch wide and 2 HU high.

Simulation of intentional and unintentional interference is a possible feature of the simulator and allows receiver designers and algorithm developers to test and enhance their applications in the presence of interference to identify, locate and mitigate for interference sources.

THORSTEN LÜCK studied electrical engineering at the universities in Stuttgart and Bochum. He received a Ph.D. (Dr.- Ing.) from the University of the Federal Armed Forces in Munich in 2007 on INS/GNSS integration for rail applications. Since 2003, he has worked for IFEN GmbH, where he started as head of R&D embedded systems in the receiver technology division. In 2012 he changed from receiver development to simulator technologies as product manager of IFEN's professional GNSS simulator series NavX-NCS and head of the navigation products department.

GÜNTER HEINRICHS is the head of the Customer Applications Department and business development at IFEN GmbH, Poing, Germany. He received a Dipl.-Ing. degree in communications engineering in 1988, a Dipl.- Ing. degree in data processing engineering and a Dr.-Ing. degree in electrical engineering in 1991 and 1995, respectively. In 1996 he joined the satellite navigation department of MAN Technologie AG in Augsburg, Germany, where he was responsible for system architectures and design, digital signals, and data processing of satellite navigation receiver systems. From 1999 to April 2002 he served as head and R&D manager of MAN Technologie's satellite navigation department.

ACHIM HORNBOSTEL joined the German Aerospace Center (DLR) in 1989 after he received his engineer diploma in electrical engineering from the University of Hannover in the same year. Since 2000, he has been a staff member of the Institute of Communications and Navigation at DLR. He was involved in several projects for remote sensing, satellite communications and satellite navigation. In 1995 he received his Ph.D. in electrical engineering from the University of Hannover. His main activities are in receiver development, interference mitigation and signal propagation.

CAST Navigation

CAST-SGX GPS Satellite Simulator

The SGX GPS satellite signal simulator from CAST Navigation provides the user with dynamic, repeatable GPS RF signals for use in the laboratory or in the field for a wide range of GPS applications. The SGX simulator is housed in a portable, lightweight, handheld enclosure measuring 7 x 11 x 3 inches and weighing just over 4 pounds.

The SGX is lightweight and portable, operates on AC or battery power, and features 16 channels of L1 C/A and P codes. Based on CAST's technology that has been developed for use in the company's larger military products, it is extremely accurate and repeatable.

The SGX is controlled via an intuitive touchscreen interface that allows the user to select, start, and stop scenarios, change screen views, and change satellite RF power levels while a scenario is running. Three test scenarios are delivered with the simulator.

XGEN Plus Scenario Generation Software. This software gives the user the ability to generate custom scenarios for use with the SGX. The software allows for complete control over GPS almanac, ephemeris, and all satellite error sources.

The user can select from a variety of vehicle types and simulate static or dynamic motion. The user can also employ antenna gain patterns and vehicle silhouettes if desired. The user can generate a customized high precision six-degree-of-freedom trajectory simply by defining a mission profile that is based on raw maneuvers, waypoints, Google Maps or a combination of these maneuver types.The new scenarios can be downloaded via USB port or SD card interfaces.

CAST has been in the GPS simulation and support business for more than 30 years, designing, developing, manufacturing, and integrating innovative GPS/INS simulators and associated test equipment for government, military, prime vendor, and consumer markets.

www.castnav.com
phone: 978 858-0130
email: sales@castnav.com

Cobham AvComm
(formerly Aeroflex)

GPSG-1000 — Portable GPS/Galileo/SBAS Positional Simulator

Designed to be a versatile yet affordable satellite simulator, the **GPSG-1000** is proving to be a vital instrument used by those validating and testing GNSS receivers in a variety of applications within the transportation, consumer electronics, aerospace and military industry segments, to name a few.

The GPSG-1000 is a single carrier, multi-channel GPS/Galileo simulator that is portable and ruggedized so it can be safely and confidently deployed in a variety of outdoor and indoor environments. The unit is available in a 6- or 12-channel configuration, and supports the following GNSS signals: L1, L1C, L2C, L5, E1, E5, E5a, E5b and SBAS (WAAS and EGNOS).

The GPSG-1000 can be directly connected to a GNSS receiver under test. It can also simulate actual "open-sky" situations whereby the unit can generate its signals through the included antenna coupler system that isolates and transmits to the UUT's antenna(s). Utilizing an integrated GPS receiver, the GPSG-1000 simulates actual time of day and date as well as the real constellation that would be available for navigation at that specific point in time. Multiple almanacs and route files can be saved to the GPSG's memory, thereby enabling current and past history dynamic motion, constellation environment creation/recreation and other significant troubleshooting capabilities. During any given static or dynamic simulation, space vehicle parametrics and health can be user controlled.

The GPSG-1000 features a touchscreen user interface that can be remotely hosted via an integrated Ethernet port. The unit uses a rechargeable, Lithium Ion battery enabling hours of untethered use, and can also be used while the battery is recharging.

ats.aeroflex.com
phone: (316) 522-4981 or (800) 835-2352
email: info-test@aeroflex.com

IFEN Inc.

NavX-NCS Professional GNSS Simulator
NavX-NCS Essential GNSS Simulator

The absolute flexibility of the **NavX-NCS Professional GNSS Simulator** allows it to be configured with up to 108 channels and all of the following signals:

- GPS L1/L2/L5 C/A & P code and L2C
- GLONASS G1/G2 standard & high accuracy codes
- Galileo E1/E5/E6 (BOC/CBOC/AltBOC)
- BeiDou B1/B2/B3
- SBAS L1/L5 (WAAS, EGNOS, MSAS, GAGAN)
- QZSS L1 & L1-SAIF
- IMES

The user is enabled to assign signals freely to any of the RF modules fitted to the simulator. This allows the same hardware to be used in a range of different configurations.

Signals may be added by software license with no need to return the hardware for upgrade.

Up to four independent RF outputs may be fitted, enabling the user to simulate multiple antenna locations simultaneously (allowing simulation of multiple antennas on one vehicle, multiple vehicles simultaneously, a mixture of static locations and mobile vehicles, and multiple antenna elements for Controlled Reception Pattern Antenna [CRPA] testing).

The comprehensive and easy-to-use Control Center operating software allows the operator to quickly create realistic test scenarios for effective testing of user equipment.

IFEN also offers the **NavX-NCS Essential GNSS Simulator**, which is available with 21 or 42 channels and is capable of simulating GPS L1 (including SBAS L1), GLONASS G1, Galileo E1, BeiDou B1, QZSS L1, and IMES. The simulator is also supplied with Control Center operating software for comprehensive scenario generation.

www.ifen.com

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phone: +49-8121-2238-20
email: sales@ifen.com

RaceLogic

LabSat 3 Triple Constellation Simulator

LabSat 3 from Racelogic is a low cost, stand-alone, battery powered, multi-constellation RF record-and-replay device, designed to assist GNSS engineers in the development and testing of their products.

With its small size and all-in-one design, LabSat 3 makes it easier than ever to collect raw satellite data in the same environment that end users experience in everyday use. This enables repeatable and realistic testing to be carried out under controlled conditions.

LabSat 3 doesn't need to be connected to a PC in order to record live-sky GNSS signals. With one-touch recording to SD card and a two-hour battery life, it can be used in any outdoor location to create real-world scenarios, for eventual replay back in the lab. As well as being able to simultaneously record or replay GPS, GLONASS, BeiDou, QZSS, Galileo, and SBAS signals, it can log CAN Bus, serial, or digital data, embedded alongside the satellite information. This additional information can then be replayed alongside the GNSS output, with synchronization to within 60 ns. A 1PPS signal can also be generated using the internal GPS receiver.

LabSat 3 can be used as a replay system out of the box with a set of 60 pre-recorded scenarios supplied as part of the package, recorded from various locations around the globe. Additionally, SatGen software, a demo version of which is available from the LabSat website, allows for scenario generation of user-defined trajectories, with precise control over velocity, heading, height, and constellation profiles. Routes are also easily created in Google Maps, and the software also supports NMEA and KML file import. SatGen gives test engineers the ability to develop their products using simulations that would be difficult or impossible to record due to geographic location or safety constraints.

LabSat 3 is available as a record and replay, or replay-only version; either one, two, or three constellation types generate a single, dual, or triple constellation file.

LabSat is currently used by many leading manufacturers of GPS chipsets, portable navigation devices, smartphones, and by major car companies in their test, development and production processes.

www.labsat.co.uk
phone: +44 (0)1280 823803

Rohde & Schwarz

R&S SMBV100A: GNSS Simulator in Vector Signal Generator

The GNSS simulator in the vector signal generator **R&S SMBV100A** is designed for development, verification and production of GNSS chipsets, modules and receivers. The simulator supports all possible scenarios, from simple setups with individual, static satellites all the way to flexible scenarios generated in real time with up to 24 dynamic GPS, GLONASS, Galileo, BeiDou and QZSS satellites.

- **GNSS simulator** with support of GPS L1/L2 (C/A and P code), GLONASS L1/ L2, Galileo E1, BeiDou and QZSS L1, including hybrid constellations.
- **Real-time simulation of realistic constellations** with up to 24 satellites and unlimited simulation time.
- **Flexible scenario generation** including moving scenarios, dynamic power control and atmospheric modeling.
- **Configuration of realistic user environments**, including obscuration and multipath, antenna characteristics and vehicle attitude.
- **Static mode for basic receiver testing** using signals with zero or constant Doppler shift.
- **Support of Assisted GNSS** (A-GNSS) test scenarios, including generation of assistance data for GPS, GLONASS, Galileo, BeiDou and QZSS.
- **Real-time external trajectory feed** for hardware in the loop (HIL) applications.
- **High signal dynamics**, simulation of spinning vehicles and precision code (P-code) simulations to support aerospace and defense applications.
- **Enhanced simulation capabilities** for aerospace applications by supporting ground-based augmentation systems (GBAS).
- **Support of other digital communications** and radio standards in the same instrument.

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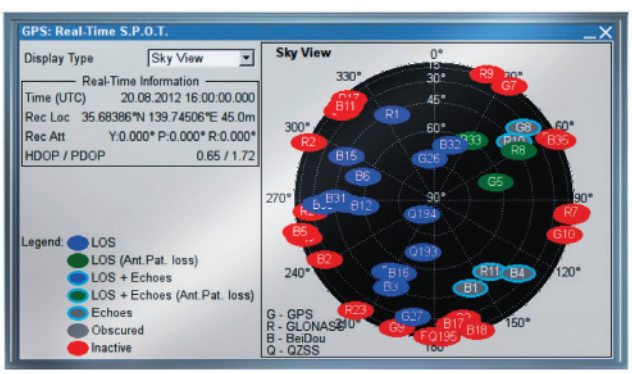

Spectracom

Afforable, Flexible and User-Friendly GNSS Simulators

Spectracom GNSS Simulators support test and development programs from simple manufacturing tests to multi-output testing across the diverse ecosphere of industries relying on GNSS technology. Spectracom's innovation allows users of any skill level full control over the GNSS constellation, vehicle motion/attitude and signal path complications such as atmospherics and multipath to develop complex scenarios. Typical test conditions include:

- Clock errors
- Data errors
- "Real-world" motion from embedded Google Maps
- In-band noise generation
- Multipath
- Signal obstructions calculated from 3D building models
- "Current time" simulation
- Real-time HIL testing
- Easy synchronization for multi-output testing
- Automative download of the current almanac
- Antenna pattern effects
- Inertial sensor testing
- Assisted GNSS testing

No dedicated PC is required. Scenarios are run and managed from the front panel, SCPI commands, or any PC/ tablet via a web interface. Users can select a flexible, field upgradeable Spectracom simulator, and then purchase the software options they need.

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

GSG-5 Series multi-constellation L1-band GNSS simulator is designed for commercial development/integration programs. If a user is developing commercial products with GNSS capability, the GSG-5 will shorten test programs with confidence.

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

www.spectracomcorp.com
email: sales@spectracomcorp.com; phone: 585-321-5800

Spirent Federal Systems

GNSS Simulators

Spirent provides simulators that cover all applications, including research and development, integration/verification and production testing.

GSS9000. The newly released Spirent GSS9000 multi-frequency, multi-GNSS RF constellation simulator can simulate signals from all GNSS and regional navigation. The GSS9000 offers a four-fold increase in RF signal iteration rate (SIR) over Spirent's GSS8000 simulator. The GSS9000 SIR is 1000 Hz (1 ms), enabling higher dynamic simulations with more accuracy and fidelity. It includes support for restricted and classified signals from the GPS and Galileo systems, as well as advanced capabilities for ultra-high dynamics. It can evaluate resilience of navigation systems to interference and spoofing attacks, and has the flexibility to reconfigure constellations, channels and frequencies between test runs or test cases.

Hardware changes can be done in the field, supported by the new on-board calibrator module. The GSS9000 is extensible and can support the widest range of carriers, ranging codes and data streams for the Galileo, GPS, GLONASS, and BeiDou systems, as well as regional/augmentation systems. Multi-antenna/multi-vehicle simulation, for differential-GNSS and attitude determination, and interference/jamming and spoofing testing are also supported.

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

GSS6425. The Spirent GSS6425 RPS quickly and simply records complex real-world RF environments, capturing both GNSS signals and atmospheric/interference effects. These environments can then be replayed repeatedly to the hardware software under test, reducing project, travel and engineering costs.

www.spirentfederal.com
Jeff Martin, Director of Sales
Kalani Needham, Sales Manager
email: info@spirentfederal.com
phone: 801-785-1448
fax: 801-785-1294

Software-Based GNSS Multi-System Simulation Environment

TeleOrbit's software-based GNSS multi-system performance simulation environment, GIPSIE, consists of a satellite constellation simulator and an intermediate frequency simulator. The digital signal simulator GIPSIE streams the software-generated signals or recorded live data exactly into the receiver's baseband processing chain to support development, test, verification, validation, qualification and certification.

Features include simulation of multi-system, multi-frequency scenarios GPS L1/L2/L5 and Galileo E1/E5/E6; simulation of jamming signals on top of the GNSS signals; simulation of Galileo PRS-like signals as well as the unencrypted GPS P-Code signals; record and replay of recorded and software generated data. GLONASS and BeiDou constellations and signals and simulation of micro-electro-mechanical sensors (MEMS) are coming soon.

TeleOrbit, *www.teleorbit.com*

Multiple RF Output Simulation

Spectracom GSG-Series GNSS Simulators have added capability to provide multiple RF outputs for advanced testing where multiple receivers or antennas are in use in a single system. Typical examples include controlled radiation pattern antennas (CRPA) or heading/attitude receivers and systems.

The intuitive StudioView software allows easy reconfiguration of test cases to change the conditions seen by one or all receivers and antennas under test — for example, adding a jamming signal to one antenna input on a CRPA receiver. Both over-the-air testing or cabled capabilities are available.

Because the simulator operates independently of PC control, the simulators can be precisely synchronized with a common clock and trigger pulse. There is no theoretical maximum to the number of RF outputs. This flexibility also allows testing multiple rovers reporting into a single control system, such as asset tracking or personnel location management systems.

This advanced feature is offered in both the L1 band GSG-5 series simulator for commercial applications as well as multi-band GSG-6 series simulator for professional applications.

Spectracom, *www.spectracomcorp.com*

Harris to Acquire Exelis

Harris Corporation has agreed to acquire Exelis Inc. for approximately $4.75 billion. The transaction is expected to close in June 2015.

Exelis is a global aerospace, defense, information and services company with a 50-year legacy. It was previously under the ITT Corporation umbrella, but spun off in 2011. Headquartered in McLean, Va., Exelis employs 10,000 people.

One of Exelis' biggest product offerings in the past year has been its Signal Sentry 1000, which detects and locates sources of intentional and unintentional interference to GPS signals and provides users with actionable intelligence. Exelis navigation payloads and components have been on board every U.S. GPS satellite ever launched and have more than 700 years of accumulated on-orbit success.

Harris is engaged in a five-year contract with Aireon LLC that will create the first global satellite-based aircraft tracking system.

GATE Facility Recertified

The German Galileo test and development infrastructure GATE has been recertified to serve as a Galileo open-air test laboratory, for receiver integrity testing (RAIM) for safety-of-life (SoL) applications, and for Galileo SIS ICD conformance of signal characteristics and signal quality.

The GATE facility, in Berchtesgaden, is operated by IFEN GmbH. Certification was conducted by TÜV SÜD, an international service corporation focusing on consulting, testing, certification and training.

GATE consists of eight transmitting stations that emit Galileo signals in the GATE test area in Berchtesgaden, as well as two monitoring stations that receive and process these signals.

The recertification included an audit of the operation processes of IFEN GmbH, with verification of implementation and adherence to process procedures for GATE operation.

The GATE certificate was extended to January 2016.


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IFEN

Spectracom Offers RTK System Testing

Spectracom's GSG-6 series advanced GNSS simulator is now available with an RTK test option. The simulator can generate RTCM 3.x correction data based on user-definable base station locations. The correction data can be passed from the simulator directly, with no need for a control PC, to the receiver under test via serial or Ethernet protocols. The RTCM messages can also be passed directly to a suitable radio for broadcast to the receiver under test.

Alternatively, two or more synchronized simulators can be used to fully test base-rover combinations. Spectracom's StudioView software allows the user to define the location of the base station and the trajectory of the rover receiver.

The feature set allows flexible testing of not only how the rover behaves under complex GNSS conditions, but also how the whole system operates when the correction data may be lost or in any error situation as the base station encounters difficult signal conditions.

This application option and multiple simulator units can improve testing of an RTK-enabled system, according to Spectracom.

PlanetiQ Plans GNSS Weather Constellation

The company PlanetiQ plans to use GNSS to make real-time weather forecasts. PlanetiQ plans to launch a commercial weather satellite constellation by 2017, composed of 12 to 18 small satellites that will capture data as GNSS satellites pass through Earth's orbital horizon.

The satellites will use radio occultation to collect data that will supplement computer models on weather, producing more accurate and timely weather forecasts and assessments, PlanetiQ said. The satellites will measure how GPS, GLONASS, and BeiDou radio waves bend as they travel through the atmosphere, a technique that provides snapshots of temperature, pressure and water vapor, as well as insight into whether solar storms are active in the ionosphere.

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Introducing the new TM-203

The TM-203 is the newest addition to our family of TraceME products.

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- Complies with additional standards for insurance benefits (e.g. SCM and Incert)
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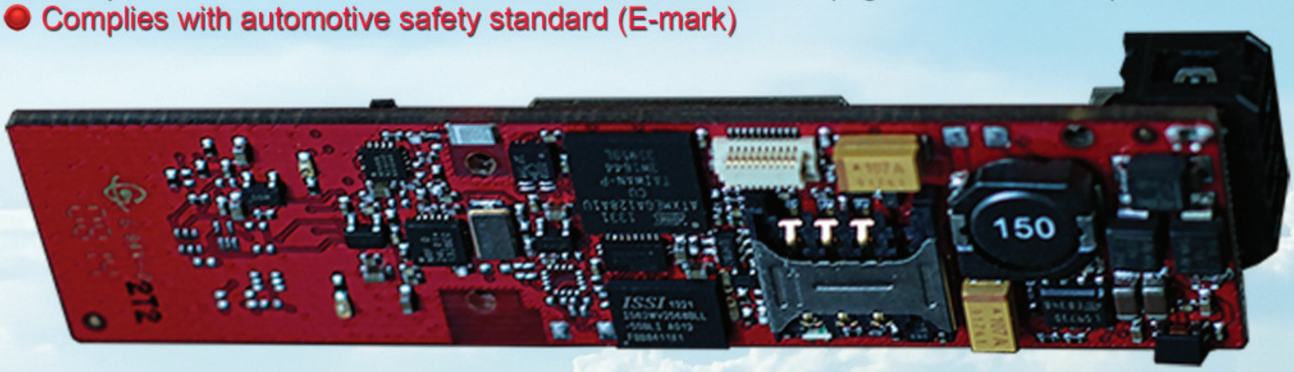

We would like to invite you to have a look around our website and get inspired by the possibilities of what KCS TraceME products can bring to your project. Whether you need a solution for personal tracking, trace and control vehicles, object protection or more advanced M2M solutions, KCS TraceME can deliver it.

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- Connect M2M to any device;
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BUSINESS BRIEFS

GNSS in Your Pocket

Trimble has introduced the R1 GNSS receiver, a pocket-sized, rugged, standalone receiver that works with iOS, Android or Window mobile handhelds, smartphones and tablets using Bluetooth connectivity. When paired with a smart device, the receiver adds professional-grade GNSS geo-location capabilities to transform consumer devices into high-accuracy mobile data collection systems.

Antenna for Harsh Environments

GPS Source has released a new GNSS antenna that is robust, lightweight, and suitable for harsh environments. The antenna was engineered for the demanding aviation environment, in both commercial and military applications. Built to military standards (MIL-STD), it is impact resistant, tolerant of exposure to dust, chemicals and jet fuels, and has the ability to withstand shock and vibration.

RTK Unit Offers Advanced Heading

NovAtel's new FlexPak6D enclosed GNSS receiver is a flexible dual-antenna unit for application developers seeking a high-precision heading-capable positioning engine for space-constrained applications.

The compact, lightweight receiver tracks GPS, GLONASS, Galileo and BeiDou. Plus, antenna placement is flexible.

OxTS Launches GNSS/INS

OxTS has released the xNAV550, its new compact and lightweight GNSS-aided inertial navigation system. The xNAV550 offers a position accuracy of 2 cm, weighs 425 grams, and is designed for use on UAVs and in other weight-constrained applications.

Visit *www.gpsworld.com* for more Business news. *Stay up to date: Follow us on Twitter @GPSWorld*

Where Are We?

Positioning in Challenging Environments Using Ultra-Wideband Sensor Networks

Zoltan Koppanyi, Charles K. Toth and Dorota A. Grejner-Brzezinska

INNOVATION INSIGHTS
with Richard Langley

QUICK. WHO WAS THE FIRST TO PREDICT THE EXISTENCE OF RADIO WAVES? If you answered James Clerk Maxwell, you are right. (If you didn't and have an electrical engineering or physics degree, it's back to school for you.) In the mid-1800s, Maxwell developed the theory of electric and magnetic forces, which is embodied in the group of four equations named after him. This year marks the 150th anniversary of the publication of Maxwell's paper "A Dynamical Theory of the Electromagnetic Field" in the *Philosophical Transactions of the Royal Society of London*.

Interestingly, Maxwell used 20 equations to describe his theory but Oliver Lodge managed to boil them down to the four we are familiar with today. Maxwell's theory predicted the existence of radiating electromagnetic waves and that these waves could exist at any wavelength. Maxwell had speculated that light must be a form of electromagnetic radiation. In his 1865 paper, he said "This velocity [of the waves] is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws."

That electromagnetic waves with much longer wavelengths than those of light must be possible was conclusively demonstrated by Heinrich Hertz who, between 1886 and 1889, built various apparatuses for transmitting and receiving electromagnetic waves with wavelengths of around 5 meters (60 MHz). These waves were, in fact, radio waves. Hertz's experiments conclusively proved the existence of electromagnetic waves traveling at the speed of light. He also famously said "I do not think that the wireless waves I have discovered will have any practical application." How quickly he was proven wrong.

Beginning in 1894, Guglielmo Marconi demonstrated wireless communication over increasingly longer distances, culminating in his bridging the Atlantic Ocean in 1901 or 1902. And, as they say, the rest is history. Radio waves are used for data, voice and image one-way (broadcasting) and two-way communications; for remote control of systems and devices; for radar (including imaging); and for positioning, navigation and time transfer. And signals can be produced over a wide range of frequencies from below 10 kHz to above 100 GHz.

Conventional radio transmissions use a variety of modulation techniques but most involve varying the amplitude, frequency and/or phase of a sinusoidal carrier wave. But in the late 1960s, it was shown that one could generate a signal as a sequence of very short pulses, which results in the signal energy being spread over a large part of the radio spectrum. Initially called pulse radio, the technique has become known as impulse radio ultra-wideband or just ultra-wideband (UWB) for short and by the 1990s a variety of practical transmission and reception technologies had been developed.

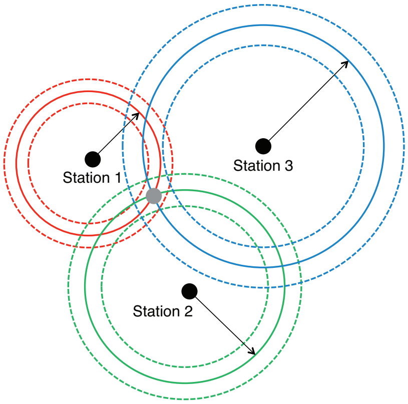
The use of large transmission bandwidths offers a number of benefits, including accurate ranging and that application in particular is being actively developed for positioning and navigation in environments that are challenging to GNSS such as indoors and built-up areas. In this month's column, we take a look at the work being carried out in this area by a team of researchers at The Ohio State University.

"Innovation" is a regular feature that discusses advances in GPS technology and its applications as well as the fundamentals of GPS positioning. The column is coordinated by Richard Langley of the Department of Geodesy and Geomatics Engineering, University of New Brunswick. He welcomes comments and topic ideas. To contact him, see the "Contributing Editors" section on page 4.

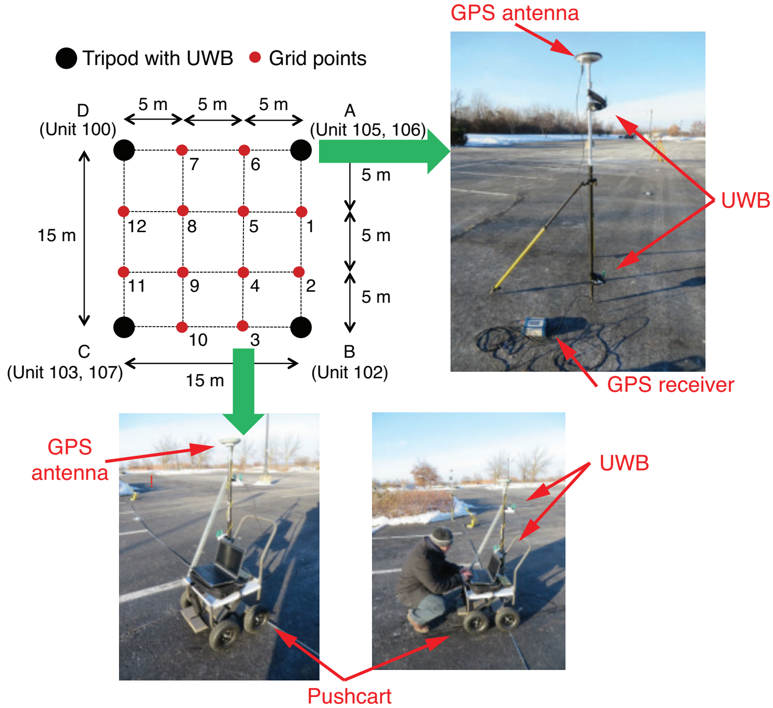
GNSS technology provides position, navigation and timing (PNT) information with high accuracy and global coverage where line-of-sight between the satellites and receivers is assured. This condition, however, is typically not satisfied indoors or in confined environments. Emerging safety, military, location-based and personal navigation applications increasingly require consistent accuracy and availability, comparable to that of GNSS but in indoor environments.

Most of the existing indoor positioning systems use narrowband radio frequency signals for location estimation, such as Wi-Fi, or telecommunication-based positioning (including GSM and UMTS mobile telephone networks). All these technologies require dedicated infrastructure, and the narrowband RF systems are subject to jamming and multipath, as well as loss of signal strength while propagating through walls. In contrast, using ultra-wideband (UWB) signals can, to some extent, remediate those problems by offering better resistance against interference and multipath, and they feature better signal penetration capability. Due to these properties, the use of UWB has the potential to support a broad range of applications, such as radar, through-wall imagery, robust communication with high frequency, and resistance to jamming. Furthermore the impulse radio UWB (IR-UWB), the subject of this article, can be an efficient standalone technology or a component of positioning systems designed for multipath-challenged, confined or indoor environments, where GNSS signals are compromised.

IR-UWB positioning can be useful in typical emergency response applications such as fires in large buildings, dismounted soldiers in combat situations, and emergency evacuations.



▲ **FIGURE 1** Circular lateration.



▲ **FIGURE 2** Outdoor test configuration.

In such circumstances, the positioning/navigation systems must determine not only the exact position of any individual firefighter or soldier to facilitate their team-based mission, but also navigate them back to safety. Under these scenarios, a temporary ad hoc network has to be quickly deployed, as the existing infrastructure is usually non-functional, damaged or destroyed at that point. The UWB-based systems may easily satisfy these criteria: (1) nodes placed in the target area can rapidly establish the network geometry even if line-of-sight between nodes is not available, (2) the communication capability allows for sharing measurements, and (3) the node positions may be calculated based on these measured ranges in a centralized or distributed way. Once the node coordinates have been determined, the tracking of the moving units can start. Obviously, the resistance against jamming makes this solution attractive for military applications.

Ultra-Wideband Ranging

At the beginning of the 21st century, the Federal Communications Commission (FCC) introduced new regulations that enabled several commercial applications and initiated research on UWB application to PNT. The current FCC rules for pulse-based positioning or localization implementations require the applied bandwidth be between 3.1 and 10.6 GHz and the bandwidth to be higher than 500 MHz or the fractional bandwidth to be more than 0.2.

The typical IR-UWB ranging system consists of multiple transceiver units, including the transmitter and the receiver components. The transmitter emits a very short pulse (high bandwidth) with low energy, and the receiver detects the signal after it travels through the air, interacting with the environment. After reaching objects, the emitted pulse is backscattered as several signals, which

Ad Hoc Network Formation for Emergency Response

- Quick deployment
- Sufficient positioning accuracy
- Robustness against interference (jamming)
- Signal penetration through solid structures

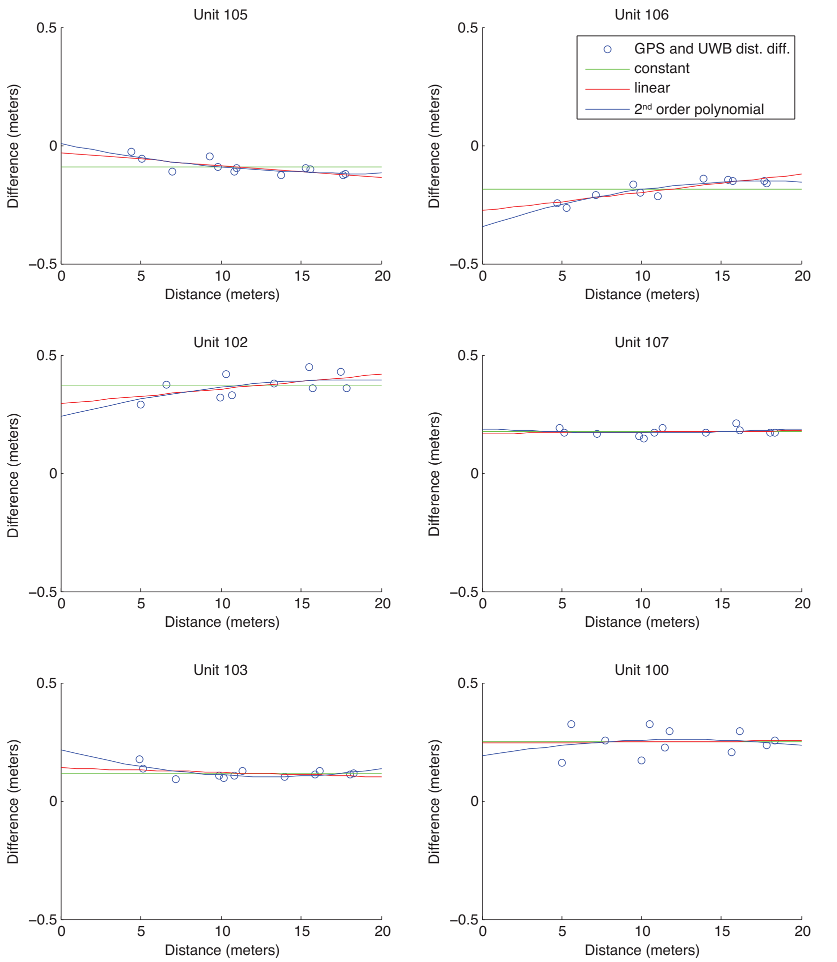
Generally, positioning systems, both local and global, require an infrastructure, which defines the implementation of a coordinate frame. For example, the national reference frames and their realizations support conventional land surveying, or the satellite and the GPS tracking subsystems, as well as the beacons in Wi-Fi systems. UWB positioning also follows the same logic; the network infrastructure defines a local coordinate system and allows for range measurements between the network nodes and the tracked unit(s).

Ad Hoc Sensor Network: Ad hoc networks are temporary, and thus, the node coordinates are not expected to be known or measured a priori; consequently, they are calculated based on measuring the ranges between the units in the initial phase, and can be updated subsequently if the network configuration changes.

Anchored Networks: The network nodes' coordinates are known. If only local coordinates are known, then to connect to a global coordinate frame, at least one node's global coordinates and a direction vector must be known to anchor and orient the network.

Anchor-Free Networks: No node coordinates are known, thus the localization problem is underdetermined. Nevertheless, the problem is still solvable, if it is extended with additional constraints.

Tracking: Once a network is established, static/moving objects can be positioned in the network coordinate system.



▲ **FIGURE 3** Calibration models.

likely reach the receiver at different times. In contrast, conventional RF signals are longer in duration, thus the backscattered waves overlap each other at the receiver, forming a complex waveform, and may not be distinguishable individually. Due to the shortness of the UWB signals, measurable peaks are nicely separated, representing different signal paths.

The wave shape of the impulse response of the transmission medium highly depends on the environment complexity due to multipath. Detections in the received wave are determined by a peak-detecting algorithm. Note that the travel time is generally determined from the first detection, as it is assumed to be from the shortest path, although other peak detection algorithms also exist.

In the experiments discussed in this article, a commercial UWB radio system was used. This sensor's bandwidth is between 3.1 and 5.3 GHz, with a 4.3-GHz center frequency. Three methods are available to obtain ranges: (1) coarse range estimation, based on the received signal strength with dynamic recalibration; (2) precision range measurement (PRM), which uses the two-way time-of-flight technique; and (3) the filtered range estimates (FRE) method that refines the PRM solution using Kalman filtering. In our investigations, PRM data were used in static situations, when both the unit to be positioned and the reference units were static (such as when determining network node coordinates), and FRE was logged in kinematic scenarios.

Localization in a UWB Network

Commercial UWB products usually provide capabilities for all three applications: communication, ranging and radar imaging. In positioning applications, identical units are used for both the rovers — that is, the units to be localized — and the static nodes of the network. The general terminology, however, is that the rover unit with unknown position is called the receiver, and units deployed at known locations are called transmitters. We will also use the terms rover and stations. The positions are typically defined in a local coordinate system. The usual ranging methods used in RF technologies, including signal strength and fingerprinting, time of arrival, angle of arrival, and time difference of arrival, are also applicable to UWB systems. **TABLE 1** lists the ranging methods and typical performance levels; the achievable accuracies are based on external references. Note that the accuracy depends on the sensor hardware and network configuration, applied bandwidth, signal-to-noise ratio, peak detection algorithm, experiment circumstances, formation and the environment complexity.

Signal Strength. The received signal strength (RSS) requires modeling of the signal loss, which is a challenging problem since signals at different frequencies interact with the environment in different ways, and thus the resulting accuracy is generally inadequate for most applications. The fingerprinting approach is also applied to UWB positioning; the signal-strength vector received from the transmitters identifies a location by the best match, where the vector-location pairs are measured in a calibration/training phase and stored in a database.

Time of Flight. The time-of-flight method requires the synchronization of

Method	Accuracy
RSS with dynamic recalibration	< 4 m**
RSS fingerprinting	>0.5 m*
Two-way time of flight	~ 20 cm*
Time difference of arrival with angle of arrival	~ 10 cm*

▲ **TABLE 1** Typical accuracy of the different UWB localization techniques. Note that the results depend on the hardware, antenna, applied bandwidth, experiment circumstances and geometric configuration; * denotes indoor environment with area coverage of a few times 10 × 10 meters, with line-of-sight conditions, and ** refers to the maximum error in the outdoor test area of about 100 × 100 meters).

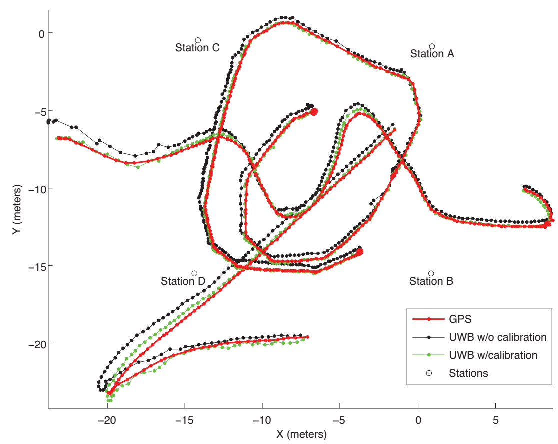
Statistic	ΔX (cm)	ΔY (cm)	ΔZ (cm)
Mean	-0.1	-0.1	64.3
Median	-0.0	-0.5	65.9
STD	9.7	13.2	91.3
Min	-27.6	-60.6	-116.2
Max	26.4	37.1	520.0
95% confidence interval	-20 to +20	-20 to +20	-100 to +300

▲ **TABLE 2** Statistical results for the coordinate components.

the clocks of the UWB units, which is difficult, in particular, in the low-cost systems. Therefore, most UWB systems are based on the two-way time-of-flight method, which eliminates the unknown clock delay between the sensors, although it also has its own challenges. The range between two units is obtained by measuring the time difference of the transmitted and received pulses plus knowing the fixed response time of the responding unit.

Computing Position in a Network. Once the ranges are known in a network environment, the position is determined by circular lateration. The principle for the 2D case with three stations is shown in **FIGURE 1**. Note that each range determines a circle around the known stations (stations 1, 2 and 3 in the figure), thus, if the stations' coordinates are known, the unknown position can be calculated as the intersection of these circles. The problem is treated as a system of non-linear equations; note that the lateration requires at least three or four nodes in an adequate spatial distribution for 2D and 3D positioning, respectively. The measured ranges, characterized by the error terms usually modeled with a normal distribution, are depicted by the dotted parallel circles around the solid "perfect" range in Figure 1. Note that this is an optimization problem, which can be solved with direct numerical approximation, such as gradient methods, or by solving the respective linear system after linearizing the problem with close initial position values.

Time Difference and Angle of Arrival. The time difference of arrival (TDoA) approach is useful when the time synchronization is not established. The unknown time delays are eliminated by subtracting the travel times between the rover and the stations, and the response time of the responding unit must be known.



▲ **FIGURE 4** Trajectory solutions.

Two Calibration Models

1. Individual sensor calibration is the approach where the sensor delays are determined separately, for example, $d_{A,B} = \hat{d}_{A,B} + f_A\left(\hat{d}_{A,B}\right) + f_B\left(\hat{d}_{A,B}\right)$, where $\hat{d}_{A,B}$ is the measured range between stations A and B, f_A and f_B are the calibration functions, and $d_{A,B}$ is the corrected range.

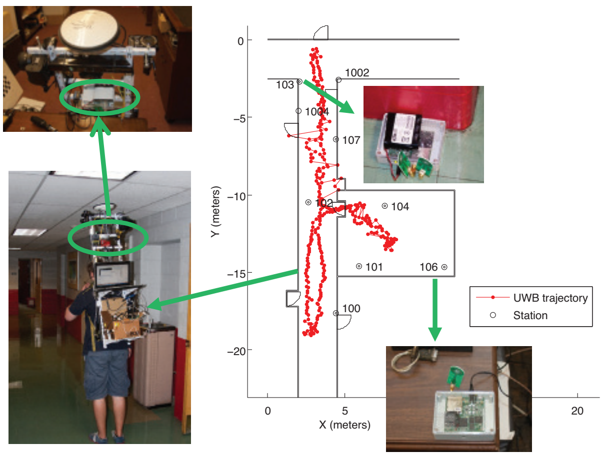
2. Joint calibration model is the approach where the calibration function does not provide the offset per station, but rather gives the relative offset between the two stations, where $d_{A,B} = \hat{d}_{A,B} + f_{A,B}(\hat{d}_{A,B})$.

The calibration model as a function of the measured distance can be constant, linear or a higher-order polynomial.

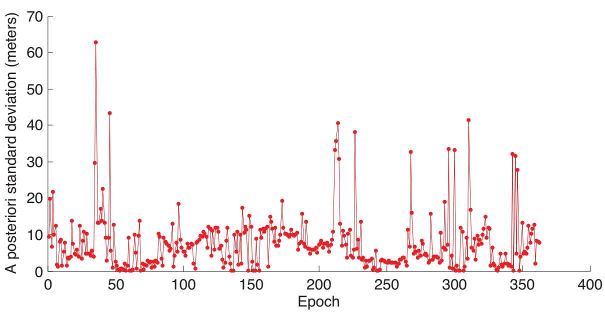
The location estimation is similar to the time of arrival case, but rather than the intersection of the circles, hyperbolic function curves representing constant TDoA values are used to determine the rover position. Also, if errors are present in the measurements, the position calculation becomes an optimization problem instead of finding the root of an equation. The TDoA can be combined with the angle of arrival (AoA). This method assumes that the set of UWB antennas are arranged in an array, and the angle can be calculated as the time difference of the first and the last detection from different antennas of the array.

Statistic	Point 1002		Point 1004	
	X (cm)	Y (cm)	X (cm)	Y (cm)
Mean	-12.86	+8.6	+13.5	+53.5
STD	+27.9	+26.3	+48.7	+28.4
Median	-9.0	+12.0	+4.0	+49.0
Min	-197.5	-158.0	-110.9	-2.0
Max	+4.0	50.0	+177.0	+142.0

▲ **TABLE 3** Differences between the UWB position estimations and the correct coordinates at points 1002 and 1004.



▲ **FIGURE 5** Indoor test configuration.



▲ **FIGURE 6** The indoor test results showing values of m_0 at the epochs.

Calibration

The ranges obtained by UWB sensors could be further improved by calibration — for example, by estimating antenna and hardware delays. In our outdoor tests, the joint calibration model (see Two Calibration Models box) was used, and coefficients of various model functions were estimated. During these tests, the UWB units were placed at the corners of a 15 × 15 meter area (see **FIGURE 2**). At two diagonal corners, two UWB units with a 1.5-meter vertical separation were installed on poles, while at the two other corners only one unit was used. These six units formed the nodes or the stations of the network. In all cases, a GPS antenna was fixed to the top of the poles to provide reference data. A pushcart with two UWB units, a logging laptop computer, a GPS antenna and a receiver formed the rover system. The reference solution was obtained by using the GPS measurements, with the accuracy around 1 centimeter after kinematic post-processing using precise satellite orbit and clock data. During calibration, the pushcart was collecting stationary data at points 1 to 12, marked on a 5 × 5 meter grid, as shown in Figure 2.

After acquiring range data between the rover and network stations, three types of joint calibration functions were investigated: constant, linear and polynomial models. The coefficients of these functions were estimated from the measured ranges and GPS-provided reference positions at all grid points. The estimated functions with respect to the six network nodes are shown in **FIGURE 3**. Our hypothesis was that the accuracy is assumed to depend on the rover-station distance, and thus, the detected discrepancies between the rover and reference points are expected to be higher if the distance is larger. The results indicate that a constant correction (that is, an antenna delay) is generally sufficient, indicating that the calibration may be applicable to similar installations. In some cases, a linear trend (a distance dependency) may be recognized due to slight data changes, but the observed regression lines are either increasing or decreasing, which clearly rejects the distance-dependency hypothesis. The linear and second-order polynomial functions likely model only local effects. The corrections provided by these functions depend on the environment, and consequently, are valid only in that configuration and where they were observed.

Error surfaces, derived as the approximation of a second-order surface from the residuals at the grid points between the receiver and the six station units, show that the discrepancies can be as large as 0.5 meter. Calibrated results using the constant model show that all the discrepancies are less than 10 centimeters with an empirical standard deviation of 3.6 centimeters. This suggests that, at least, the constant-model-based calibration is needed.

Tracking Outdoors and Indoors

If the coordinates of the network nodes and the calibration parameters are known, the location of the moving rover can be calculated with circular lateration. The experiment described in this section is based on the same field test as presented earlier. For assessing the outdoor tracking performance, a random trajectory of the pushcart inside and outside of the rectangle defined by nodes was acquired (see **FIGURE 4**). The reference trajectory was obtained by GPS and the UWB trajectory was calculated with circular lateration.

TABLE 2 presents a statistical comparison of the coordinate component differences between the GPS reference and the UWB trajectory based on calibrated ranges. The mean of the X and Y coordinate differences are around 0 centimeters, and their standard deviations are 9.7 and 13.2 centimeters, respectively, with the largest differences being less than half a meter in both coordinate components. Note that the vertical coordinates have large errors due to the small vertical angle, which translates to weak geometric conditions for error propagation.

Indoor UWB positioning is more challenging than outdoor, as propagation through walls modifies the RF signals resulting in attenuations and delays. Furthermore, the geometric error propagation conditions (that is, the shape of the network) may also reduce the quality of positioning.

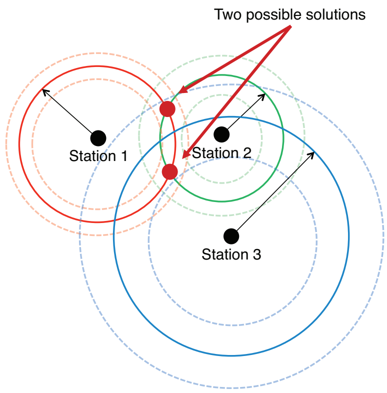
In the indoor tests, a personal navigation system demonstration prototype built in our lab (shown in FIGURE 5) was used as a rover. During the tests, the person was moving at a normal pace, and the rover unit recorded the ranges from the reference stations. Concerning the network, two point types are defined: (1) network nodes depicted by a double circle in the figure, which are used in the tracking phase; and (2) reference points marked by a single circle, which support the validation of the positioning results.

Since no reference solution was available during the indoor testing, the calibration method's consistency was evaluated based on the relative or internal accuracy metric, which is the a posteriori reference standard deviation error:

$$m_0 = \sqrt{\frac{\boldsymbol{v}^{\mathrm{T}}\boldsymbol{v}}{r}}$$

where $\boldsymbol{v}$ is the vector of residual errors and $r = \dim\left(\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A}\right) - \operatorname{rank}\left(\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A}\right)$ is the degrees of freedom of the network with $\boldsymbol{A}$ being the design matrix describing the geometry of the network. The m_0 values are shown in FIGURE 6. This parameter describes the statistical difference of the measurements from the assumed model (circular lateration). The average m_0 is 7.6 centimeters without calibration, and higher if any of the outdoor calibration models are used.

To estimate the absolute or external accuracy without a reference trajectory, points 1002 and 1004 were used as checkpoints with known coordinates. Obviously, these points were not part of the network. The UWB rover unit was placed at these points, and data were acquired in a static mode. The coordinates were continuously calculated after measuring at least three ranges. TABLE 3 presents the statistical results. Note that the average is not 0, thus the result is biased, indicating that the signal penetration and/or multipath effects are present in this complex indoor environment. Also, note that no calibration was performed, as no indoor calibration results were available, and using the outdoor calibration models only decreased the positioning accuracy. In addition, the standard deviations indicate the average m_0 is consistent with the external error for point 1002, while this hypothesis is rejected for point 1004. Taking a closer look at the results of point 1004, the ambiguity problem of the circular lateration can be observed. The random measurement error can be large enough to cover two possible intersections in circular lateration, thus the estimator may oscillate between two solutions. Two main causes for this ambiguity are a weak network configuration and the large ranging errors (see FIGURE 7).



▲ FIGURE 7 Ambiguity of lateration.

Ad Hoc UWB Sensor Network

We have also carried out tests on an indoor ad hoc sensor network using different coordinate estimation methods. Indoor distance measurements typically do not follow a normal or Gaussian error distribution but rather a Gaussian mixture distribution, which demands the use of a robust estimation method. Our results showed that the maximum likelihood estimation technique performs better than conventional least squares for this type of network.

Conclusion

Ultra-wideband technology is an effective positioning method for short-range applications with decimeter-level accuracy. The coverage area can be extended with increasing network size. The technology can be used independently or as a component of an integrated positioning/navigation system. GPS-compromised outdoor situations and indoor applications can be supported by UWB in permanent and ad hoc network configurations. While UWB technology is relatively less affected by environmental conditions, signal propagation through objects or other non-line-of-sight conditions can reduce the reliability and accuracy.

Acknowledgments

This article is based, in part, on the paper "Performance Analysis of UWB Technology for Indoor Positioning," presented at the 2014 International Technical Meeting of The Institute of Navigation, held in San Diego, Calif., Jan. 27–29, 2014.

Manufacturer

The experiments discussed in the article used a **Time Domain Corp.** (*www.timedomain.com*) PulsON 300 UWB radio system.

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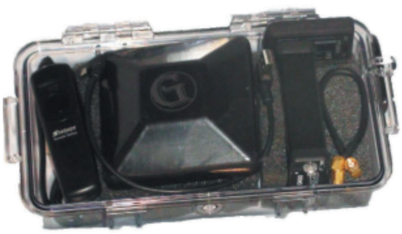
The Precision to Carry On

Nicholas DiGruttolo

When asked to do a small survey job overseas, we were concerned about shipping bulky and expensive survey equipment. Shipping costs are not trivial. Add to that the real possibility that your survey equipment may be confiscated by the local authorities, as ours was in Djibouti, and the cost of shipping equipment becomes a substantial part of the overall job. There should be alternatives, especially if accuracy requirements are not stringent.

Faced with this problem for a second time, we considered a new receiver system that has many advantages over conventional survey-grade GNSS receivers: It is small, lightweight and low-cost without sacrificing performance, making it ideal for precision surveying in remote areas of the world and for traveling to the job site by commercial airline. All the components, including the tripods, rods and batteries, are constructed from commercial off-the-shelf (COTS) components. A complete base and rover kit fits in a baseball bag and weighs less than 10 kilograms. The kit is sized and approved as carry-on luggage.

The system is scalable from a simple single-frequency semi-mobile receiver for control networks and some semi-kinematic mapping applications, to a dual-frequency network RTK solution.



▲ **COMPLETE SURVEY SET** including GNSS receiver, antenna, battery and cables, fits in a small handheld plastic case.

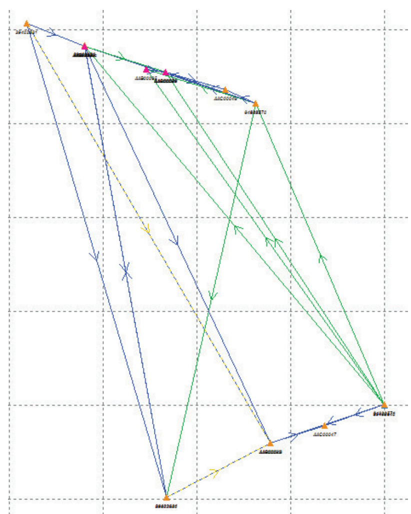
The system comes with free processing software that supports carrier-phase relative positioning in real time and post mission, as well as precise-point positioning (PPP) and CA-code differential correction. The software is designed with a simple user interface for easy selection of base and rover data or automatic data download of the closest Continuously Operating Reference Station (CORS) from the U.S. National Geodetic Survey database.

The system fills a gap between survey applications, where centimeter-level precision is an absolute necessity, and mapping applications, where meter-level is tolerable. The product offers sub-foot precision in most cases and centimeter precision in ideal situations.

Our team recently performed topographic mapping of an oil refinery site in Saudi Arabia and surveyed a precise-elevation network in Sarasota, Fla., to research the effects of sea-level rise. The small size of the COTS components simplified transport to Saudi Arabia, eliminating additional airline baggage fees and easing import through customs. Researchers performing the sea-level study reduced field time by increasing the number of receivers needed to observe a robust vertical control network.

Oil Refinery. The oil refinery project entailed mounting a GNSS antenna on the roof of an off-road vehicle and driving multiple transects around the 18-kilometer perimeter of the site to record the elevation of the terrain. Kinematic data was recorded at 1 Hz using a GPS-only version of the

▲ **COMPONENTS** easily pack into a baseball-style case.



▲ **FIGURE 2** Sea-level rise monitoring network showing increased tie points and redundancy as a result of adding the extra lightweight precision receivers to the survey-grade receivers.

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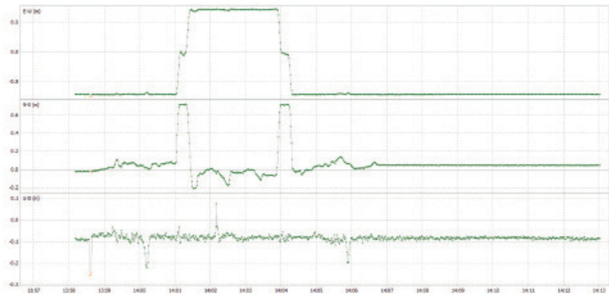

▲ **FIGURE 1** Antenna location difference in the sub-decimeter range between the survey-grade system and the compact low-cost system. Note: A 0.6-m offset is to be removed from the difference, as the two antennas were mounted 0.6 m apart in the vehicle driving direction.

single-frequency receiver. Baseline length to the local reference station varied from less than 1 kilometer to about 10 kilometers. The site was open desert with no overhead obstructions or sources of multipath other than the roof of the vehicle on which the antenna was mounted. Post-processing and comparison to simultaneously collected data from a high-precision survey-grade receiver revealed positional accuracy of about 5 centimeters horizontal and 10 centimeters vertical, when the system's trajectory was compared to the truth trajectory provided by the survey-grade receiver. **FIGURE 1** shows the difference between the two trajectories. The system's antenna was 2 feet away from the survey-grade antenna along the driving direction of the vehicle; the trajectory was mostly in the north-south direction and hence the 0.6-m offset in the plot!

Sea Level. The sea-level-rise study required a high-accuracy vertical control network to cover a 2,500 hectare area. The purpose of the network is to determine the shortest term effects of sea-level rise with a rate of 1.8 millimeter/year in the affected area. Ten benchmarks were established throughout the area of interest, and a robust network of static observations was performed with a combination of two dual-frequency and two single-frequency receivers. The single-frequency receivers were GPS-only units where two standard 4-inch patch antennas were mounted on rods adjusted to a 0.9-meter height. The addition of two receivers provided greater redundancy and a stronger network solution in much less time than would have been possible with only one pair of survey-grade receivers. **FIGURE 2** shows the addition of several loop ties to the network as a result of adding the two roving, lightweight receivers.

Manufacturers

The system described in this article is the G1 system developed by **Geomatics USA, LLC** (*www.geomatics.us*; see also *www.navtechgps.com*).

NICHOLAS DIGRUTTOLO works as a field surveying manager for JBrown Professional Group Inc., Northrop Grumman Corporation, and has recently become vice president of surveying.