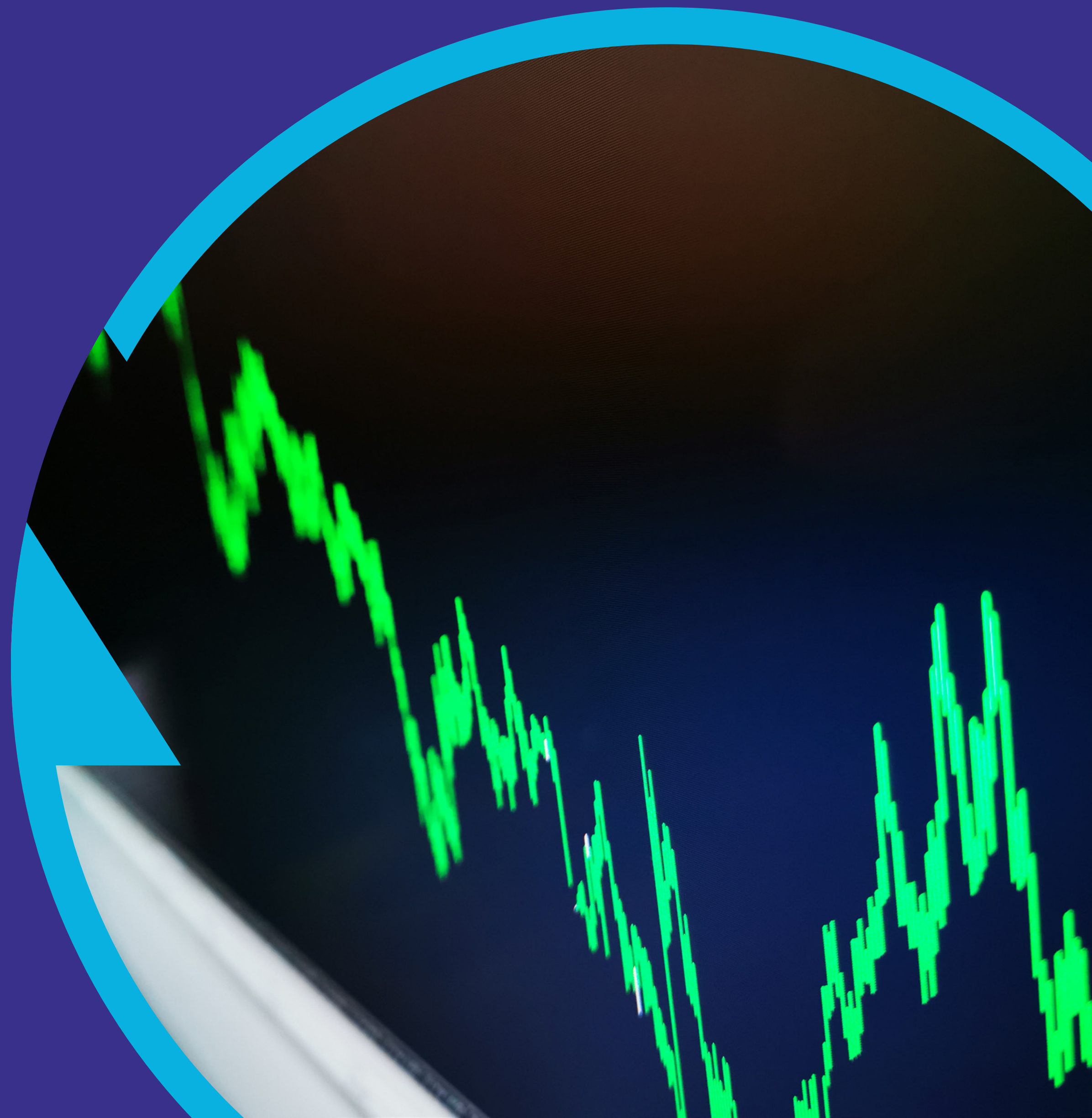
A SPIRENT E-BOOK

How to create a realistic GNSS test environment in the lab

Considerations for maximizing realism in GNSS simulation, recording and playback



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Introduction: The need for realism in lab-based GNSS testing

The ultimate aim of GNSS testing is to understand how a GNSS-enabled device will perform in the real world. The earlier it can be tested in a 'realistic' environment, the sooner any performance issues can be identified and fixed – before the device is in production or, worse, in the hands of users.

But realism in testing doesn't mean taking a prototype device outside and seeing how well it works. While the real environment is as real as it gets, it has many drawbacks for testing purposes because many of its characteristics are unknown and uncontrollable.

If your prototype drone loses reception on an outdoor test flight, for example, how do you know what caused that signal loss? Was it radio frequency (RF) interference in the environment? Was the signal blocked by a nearby structure, or by part of the drone's chassis? Is there a flaw in the antenna design? With a live sky environment, it's hard to know for sure.

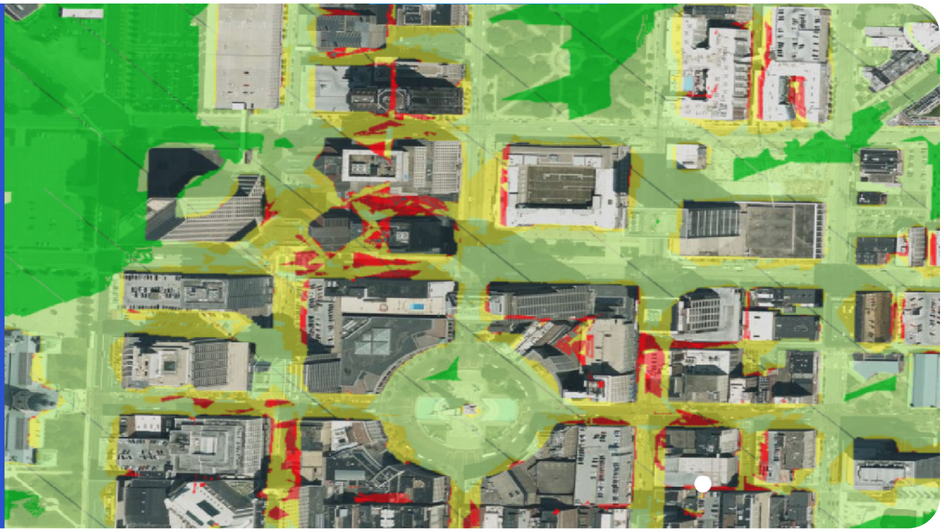
In this eBook: Guidelines for achieving maximum realism in the lab

While real-world testing does have an important place in the product lifecycle, it's typically at the verification stage, after the majority of performance issues have been ironed out. So how can you achieve enough realism in the lab to allow you to find those issues, while still having full knowledge and control of the environment?

In this eBook, we'll define what realism means in lab-based testing, and provide some guidelines for ensuring your GNSS simulation and GNSS record & playback equipment creates the most realistic test environment possible.

Did you know?

Spirent's GNSS Foresight is a series of cloud-based forecasting solutions that use 3D maps and precise orbital information to enable users to find out where and when GNSS will be reliable.



1. Defining realism in lab-based GNSS testing

Through simulation and record & playback systems, users are able to access the state-of-the art in test environments for GNSS. However, there remains a gap between lab-based testing and testing GNSS in the way the end users experience the device or system in the real world — whether that is using location services in urban environments or safety-critical applications in vulnerable RF environments. Bridging this gap represents a great opportunity for developers. As more testing becomes more representative, a greater proportion of testing can be carried out in the cost-effective and repeatable environment of the lab — reducing the time for each development cycle.

Attempting to recreate the real world in the lab, in all of its richness and with its endless variables, is not a viable solution for most developers. Even the most intricate digital twin cannot incorporate 12,500 miles of propagation and every transient noise signature seen in an urban environment. However, what is possible is to bridge this gap by incorporating more accurate models into simulation scenarios. Models of transmitters (GNSS satellites inclusive of data), receivers (GNSS receivers), propagation channels (physical environment) and vehicle structure and dynamics can all contribute to improving the realistic behavior of the simulation environment. With this in mind, realism in this eBook can be defined as a significantly improved replication of the real-world environment – a greater degree of realism than would previously have been viable.

Improving the realism and fidelity of the overall simulation so that it recreates the sort of conditions encountered in the real world requires that the contribution of each of the component models is considered and improved separately. For testers, this involves considering the quality, consistency and performance of test instruments, as well as the specialist tools used to enhance the test environment.

Key principles for realistic GNSS testing in the lab...

Creating a realistic yet fully deterministic test environment means ensuring four things:

1. That simulated GNSS signals faithfully replicate the real signals, while giving users ability to control, repeat and modify.
2. That there is tight coupling between the software and hardware.
3. That individual elements of the synthetic environment mirror the characteristics and behavior of their real-world counterparts as closely as possible.
4. That more accurate external data/ models can be used, whenever accessible.

At the same time, engineers need to have confidence that any errors or anomalies observed in the test results are produced by the device under test (DUT), rather than by the test equipment. That leads to one more key principle to balance against the drive for 'true' realism:

5. All simulation equipment should be an order of magnitude more accurate than the expected performance of the DUT. This is the balance of control against true realism – without this clarity and control, lab-based realism loses a key benefit.

The more closely these five principles are observed by the test equipment vendor, the more effective the testing will be at highlighting potential performance issues and uncovering their root cause. For developers and integrators of GNSS receivers, maximizing the realism of lab testing means more potential issues can be identified earlier in the product lifecycle, which in turn means:

- Faster time to market, as reworks can be done more quickly at the development stage
- Lower test costs, as less field testing is needed
- Less risk of an issue going undetected until the device is in the hands of users
- Fewer safety concerns

What to consider when creating a realistic GNSS test environment

It wouldn't be feasible to cover every aspect of building realism into testing in one eBook, so we'll look at a few fundamentals. Importantly, the first step towards this goal is to ensure the test equipment is of the highest fidelity. There are many aspects to consider before aiming to make lab testing as realistic as possible, and not all will be clearly documented in manufacturers' spec sheets. In the next sections, we'll set out what to consider in terms of simulation and RF record & playback.

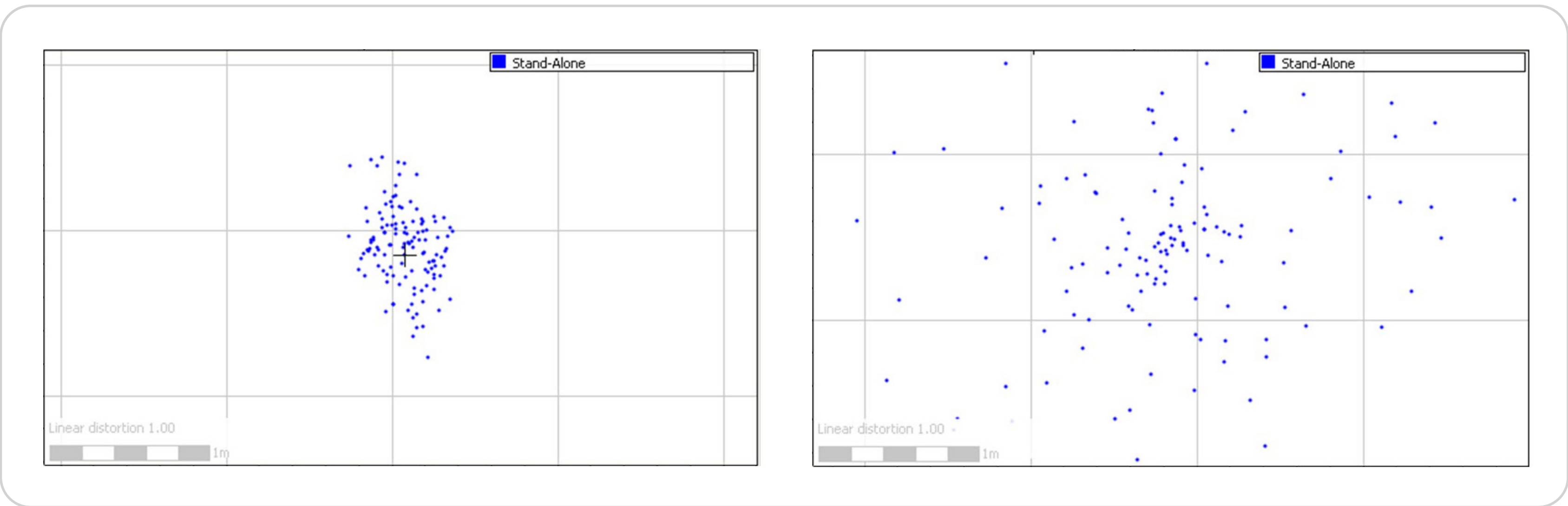
2. Considerations for realistic simulation

Signal modeling

In GNSS testing, all simulation starts with the re-creation of the GNSS signals. While the receiver will never encounter the 'pure' signal in the real world, a simulator that accurately models the signal architecture provides a reliable baseline against which the impact of other factors can be confidently measured.

If the signals are not accurately modeled in the simulator, they may produce spurious RF emissions that introduce inaccuracies into the test results. Without knowing the accuracy of the simulated signals, engineers can't know whether any anomalies were caused by the faulty signal or by the DUT, undermining the integrity of the test results.

For more about how to evaluate signal accuracy in a GNSS simulator, read our eBook: How to Choose a GNSS Simulator.



Pseudorange accuracy of Spirent (L) and non-Spirent (R) simulators

ICD implementation and constellation modeling

The implementation of the Interface Control Document (ICD) is where realism starts to be layered into simulation. Each constellation's ICD describes the way the signal should be seen by the receiver, taking into account real-world factors like atmospheric interference, clock bias and ephemeris errors.

A good simulator will accurately implement the parameters set out in the ICD, and the manufacturer will ensure that any further updates to the ICD are implemented as they are published (or even before they are published, depending on co-operation with relevant bodies) – for example, when new space vehicles (SVs) are added to the constellation. Staying current with ICD updates means the simulator is always generating signals that accurately reflect the real-world or planned operation of the constellation in question.

In some cases, however, the parameters set out in the ICD may not provide a sufficiently realistic representation of constellation behavior for the test at hand. Nav data generation is one example. Typically, orbital navigation data is populated in the simulator directly from the satellite motion definition in the ICD. While this is accurate enough for the vast majority of cases, some more complex scenarios can expose limitations in this approach.

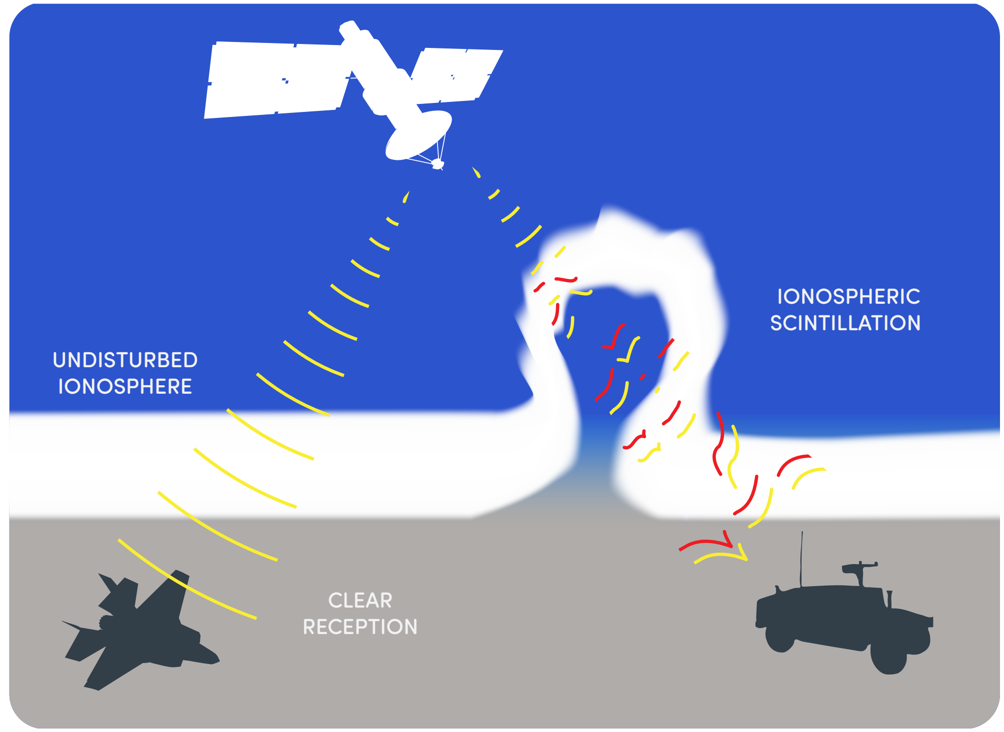
In particular, problems can arise when motion is defined using parameters not present in a particular navigation message, causing the satellite position computed by the user equipment to differ from that generated by the simulator. In this case, a more computationally intensive curve-fitting approach produces more 'realistic' results, by allowing users to see ephemeris and clock errors that are highly representative of those observed under live sky conditions.

Space weather and atmospheric effects

GNSS signals are subject to a variety of space weather and atmospheric interference effects. While ICDs provide mathematical models for simulating the impact of space weather and atmospheric interference, these are necessarily 'unrealistic' as the real space weather environment is constantly changing and largely unpredictable.

However, some test scenarios may require greater realism than is possible with standard simulator control software. An aerospace manufacturer may need to model the impact of solar activity on spacecraft navigation systems, for example, or an agri-tech company may need to assess the impact of ionospheric scintillation on a precision agriculture system used near the equator.

For use cases like these, the ability to model and simulate space weather and atmospheric effects more realistically in the lab can bring down the cost of field testing and reduce time to market.



Local environment

Simulation of the local environment is an area where greater realism in the lab can bring significant time savings and cost efficiencies into the test process.

Many environmental factors affect the performance of a GNSS receiver, but not all simulators are capable of modeling them in a realistic fashion. Key areas for consideration include:

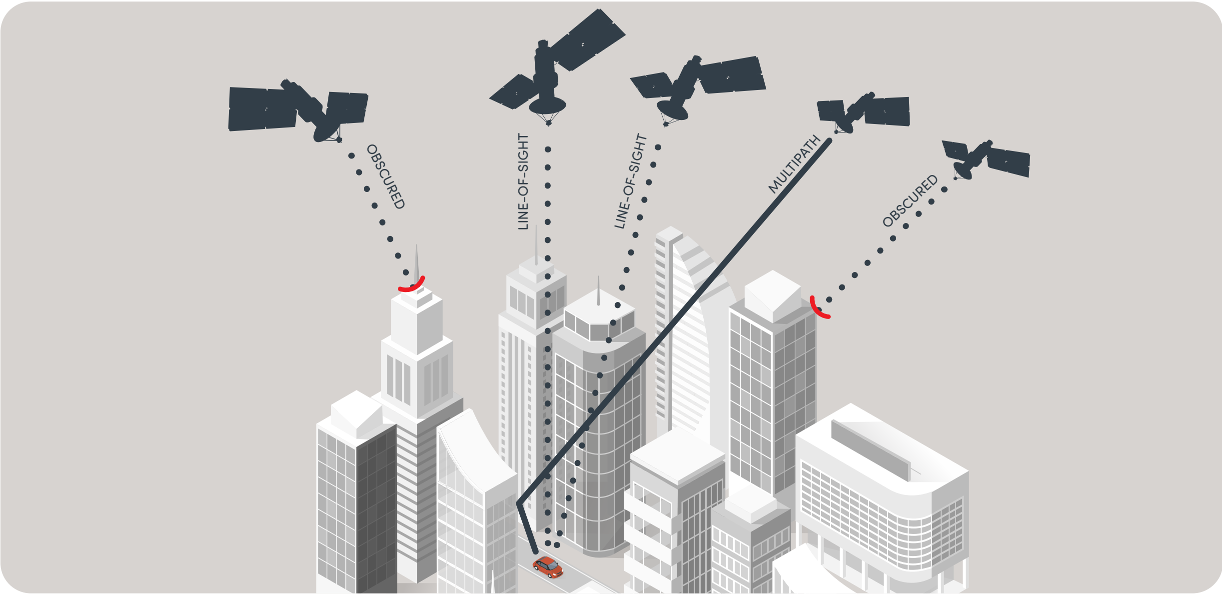
Multipath and obscuration: As no two locations on Earth are the same, multipath signals and signal blockages caused by structures in the environment occur differently everywhere. Simulation software usually relies on statistical modeling to create multipath and obscuration effects for a typical 'downtown location', but the patterns produced bear no resemblance to any real-world location.

For receivers that have to perform reliably in built-up urban locations, the need to understand the impact of multipath and obscuration often means drive testing in different cities and at different times of day. That's an expensive and time-consuming undertaking, and because the signal environment isn't both known and repeatable, test engineers can never be sure exactly how it has affected the receiver.

More of that work can be brought into the lab by using 3D environment modeling and ray tracing software to model the signal environment in geo-realistic locations, or even specific places. The most advanced software can even take into account building materials used at the simulated location, to model how well signals pass through them.

Interference: Many types of interference can affect receiver performance, from deliberate jamming and spoofing to out-of-band emissions from radio, TV and cellular transmitters. Simulating these interference effects realistically in the lab can inform efforts to harden the receiver against real-world threats.

As the illegal use of RF jammers grows, for example, access to a continually updated library of observed jamming waveforms – whose behavior can be controlled in the simulator – can be useful to evaluate the receiver's resilience in the face of this evolving threat.

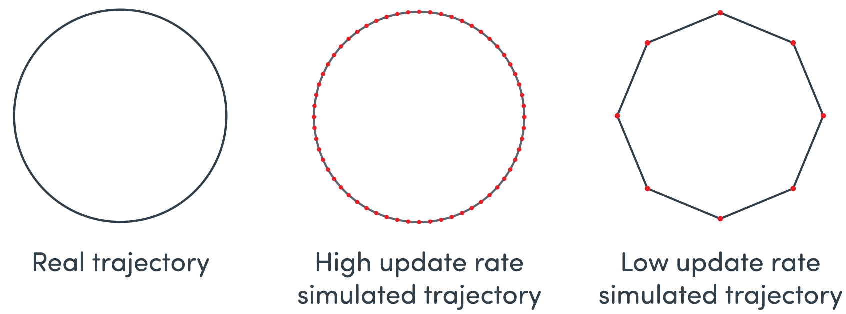


Vehicle modeling

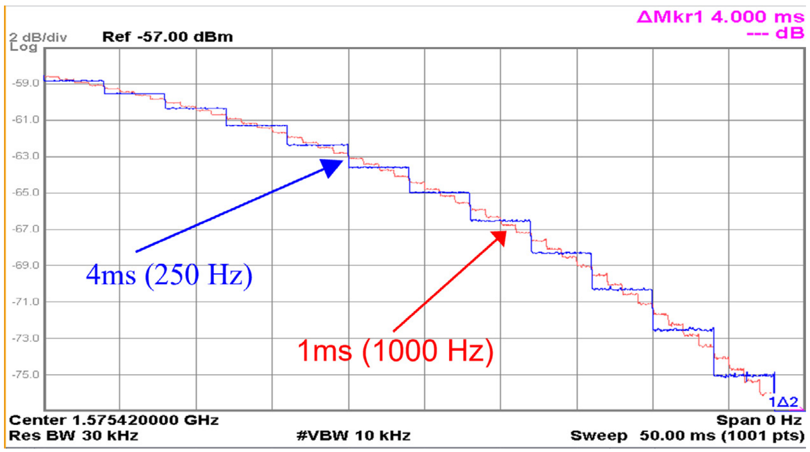
For receivers destined for use in a vehicle, the more realistically the vehicle's characteristics and dynamics are reflected in the simulator, the more accurate and insightful the test results will be. Key areas for consideration include:

Vehicle structure: Depending on where the antenna is placed in or on the vehicle, GNSS signals may be blocked or multipathed by elements of the vehicle body. Accurately modeling the structure of the vehicle in relation to the antenna can provide a good guide to any potential issues.

Motion and trajectory: Testing will want to consider how the receiver performs when the vehicle is carrying out a range of manoeuvres. Simulated signals must be able to keep pace with vehicle dynamics in scenarios such as rapid acceleration and rapid changes of direction (jerk). For highly dynamic scenarios, the faster the simulator's update rate, the more accurately it will be able to plot the attitude and position of the vehicle. A lower update rate sees fewer points mapped on the trajectory, making it angular and unrepresentative, whereas a higher update rate will closely follow the true path.



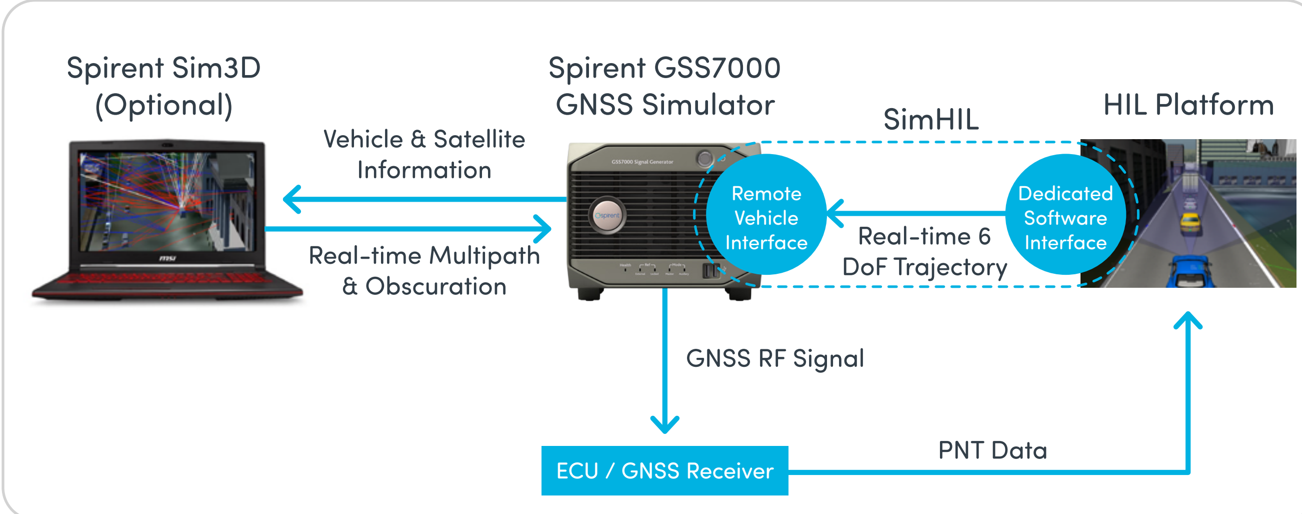
Vehicle circular motion at different update rates



Data sampled at different update rates

Hardware in the loop: When testing with hardware in the loop, to achieve realistic measurements, signal simulation must stay in sync with the motion and trajectory data generated by the hardware under test. It must also be able to handle late-arriving or missing data without introducing signal errors. That requires ultra-low latency between the simulator and the other elements of the test setup, both for receiving and processing motion data and for delivering the simulated signal back to the DUT.

While it can be possible to remove the impact of latency in post-processing, this can only be done accurately if the latency remains within certain bounds (which should be specified by the simulation software vendor). High levels of variance between the simulated signal and the trajectory of the vehicle as interpreted by the other elements in the HIL configuration will reduce the accuracy of the measurements, potentially producing misleading results.



3. Considerations for realistic RF record & playback

RF record & playback is often the primary method of bringing realism into the lab. In some ways it represents the best of both worlds, combining the richness of the real-world environment with the repeatability needed for scientific lab testing.

Making recordings of the real environment in different locations can significantly cut down on drive testing costs and timescales. Record & playback can also be extremely useful for testing devices designed to operate in one specific location, such as a mine or container port.

However, not all record & playback equipment offers the same level of realism. If the aim is to achieve maximum similarity to the live sky environment, there are several factors to consider when selecting and using a record & playback device.

Selecting a record & playback system

Record & playback systems vary greatly in technical sophistication, affecting the quality of recording and playback. Elements to consider include:

Bit depth: The resolution at which the record & playback device records the environment is of critical importance. GNSS signals are very weak compared to surrounding noise, so a unit that only records at 1 or 2 bits, for example, risks losing the signal entirely in a noisy environment.

The bit depth of the recording must therefore be higher than the bit depth of the receiver, otherwise it will not provide a realistic representation of the environment from the receiver's point of view, and the receiver's ability to distinguish signal from noise will not be tested.

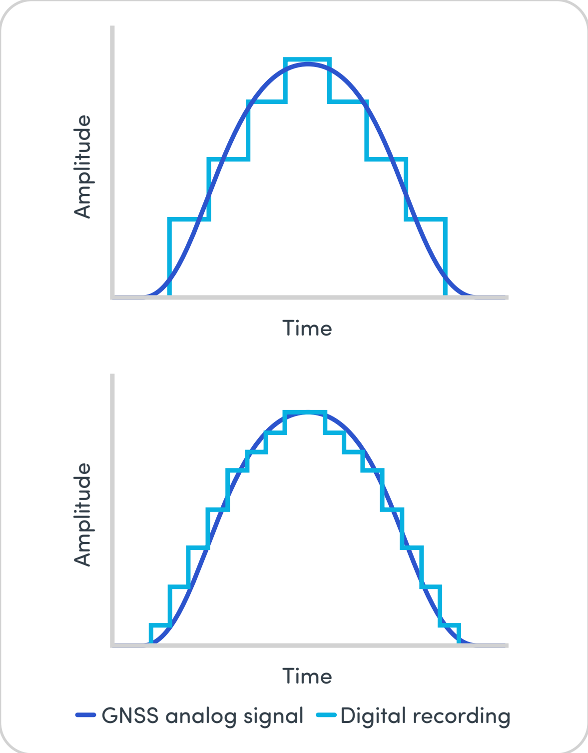
Dynamic range: Of equal importance to bit depth is the dynamic range of the record & playback unit, which indicates the range of signal strengths the unit is capable of recording.

If a unit has a dynamic range of 40dB, for example, it will record everything within 40dB of the loudest signal in the environment. If the GNSS signal is 60dB quieter than the loudest signal in the environment, a record & playback unit with 40dB of dynamic range will not pick it up.

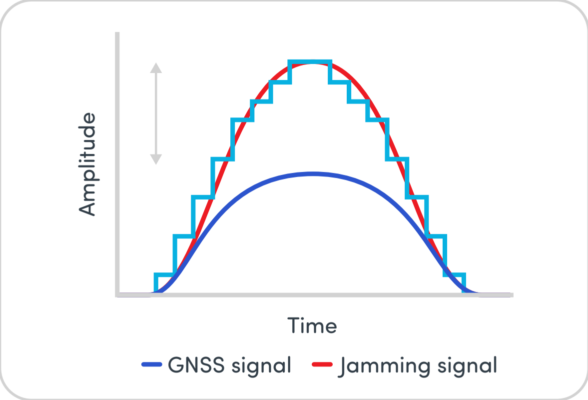
Dynamic range is especially important when it comes to testing receivers designed to filter out interference signals. The range must be high enough to preserve the GNSS signals even in the presence of much noisier signals in the environment.

Design and build: The quality of the design and build of the record & playback unit is an important but often overlooked consideration. A lower-quality unit can introduce jitter into the recording caused by noise from its own internal componentry – which is noise that was not present in the real-world environment as it was recorded.

A high-quality record & playback unit will come with assurance that components like the internal power supply will minimize jitter. However, as components degrade over time, older units should be regularly re-assessed to ensure that internal noise levels are not introducing anomalies at the record or playback stage.



Visualizing the difference in recording with lower and higher bit depths



High dynamic range enables recording of both GNSS and powerful interference concurrently

Using a record & playback system

The aim of record & playback is to create a repeatable version of the live sky environment for scientific lab testing. To be truly repeatable in the scientific sense, the playback must be identical to the recording and identical to every previous time it has been played.

If it's not identical, it's hard to know whether differences observed in receiver performance are due to the receiver or to the playback, reducing the reliability of the test results. Here are some factors to consider that can affect the realism of RF playback:

Oscillator quality: The quality of the oscillator in the record & playback unit is integral to the fidelity of the replay. With a lower-quality, temperature-compensated oscillator (TCXO), for example, recordings made at one temperature (e.g. outdoors at -2°C) may not replay accurately when the unit is at a different temperature (e.g. indoors in a warm lab).

And if the oscillator in the receiver is the same type as the oscillator in the record & playback unit, any oscillator noise will be magnified three times in the output measurements after recording and playback. For that reason it's essential to have a higher-quality oven-controlled oscillator (OCXO) in the record & playback unit than the receiver.

Replay on a different unit: Recording the environment with one unit and replaying it on another risks introducing noise from the second unit that will affect the integrity of the test results. Any variation in componentry between the two units may also affect the integrity of test results.

Spirent's GSS6450 record & playback system brings the real world into the lab in dynamic detail

4. Spirent: Committed to realism in GNSS testing for 35+ years

We hope we've demonstrated in this eBook that the level of realism matters when using lab equipment to evaluate the performance of your GNSS receiver. The more realism you can bring to your lab testing, the more issues you'll be able to identify and fix before you take the device out for verification testing in the live sky environment.

For the past 35 years, Spirent has been committed to helping GNSS test teams achieve maximum realism without sacrificing knowledge or control of the test environment. We continually work with customers in some of the most demanding sectors to develop hardware, software and models that reflect the real world as accurately as possible.

To give just a few examples, spacecraft can't be field-tested, so our space agency customers must uncover as many issues as possible through lab simulation. Customers in the military domain require simulators with fast hardware update rates to stay in sync with the acceleration and jerk dynamics of drones and guided munitions. And automotive customers testing the next generation of self-driving vehicles require highly realistic modeling of multipath and obscuration effects as well as highly realistic and reliable HIL integration.

Our products reflect the need for realism in these and many other industry sectors, and we are continually refining and developing them in line with emerging customer needs.

TALK TO US ABOUT BRINGING MORE REALISM TO YOUR GNSS TESTING

If you would like to talk to Spirent about any aspect of bringing realism into your GNSS test lab, we would be happy to discuss and advise. Please get in touch with us at www.spirent.com/contact.

About Spirent Communications

Spirent Communications (LSE: SPT) is a global leader with deep expertise and decades of experience in testing, assurance, analytics and security, serving developers, service providers, and enterprise networks. We help bring clarity to increasingly complex technological and business challenges. Spirent's customers have made a promise to their customers to deliver superior performance. Spirent assures that those promises are fulfilled. For more information visit: www.spirent.com

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MCD00463 | Issue 1-01 | 02/22