Why Simulate?

What is a GNSS Simulator? Why should you use one for testing?

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Introduction

The number of applications using Global Navigation Satellite System (GNSS) technology is continually increasing. So too is the diversity of these applications. Many applications are pushing the requirements of GNSS technology further than ever before. In some cases it is necessary to augment GNSS technology with other systems to meet the performance requirements of a particular application.

For GNSS to succeed as a state-of-the-art technology, the design of the various parts of the system - in particular GNSS receivers - must be of a high standard that ensures reliable performance.

To enable this, it is important that the product development process is based on proper testing from concept to production. This White Paper discusses this testing, and why RF simulation - which has been the standard method for over 20 years – should be the chosen method. It also explains the concept of simulation and gives examples of different simulators for different test applications.

This White Paper sets out to provide designers, developers, integrators and testers of GNSS receivers or systems an overview of the technical benefits offered by GNSS simulation and explain the cost benefits to procurement managers, project managers and financial managers who need to construct business cases for projects involving GNSS technologies.

What is a GNSS RF simulator?

Global Navigation Satellite System (GNSS) is a general term for a system that provides navigation and other services to users worldwide. Each GNSS employs a constellation of satellites, which broadcasts signals that are processed by GNSS receivers to determine location, speed, and time for users anywhere in the world. Examples of GNSS in operation or being developed include GPS, GLONASS, Galileo and Compass.

A GNSS simulator provides an effective and efficient means to test GNSS receivers and the systems that rely on them. A GNSS simulator emulates the environment of a GNSS receiver on a dynamic platform by modelling vehicle and satellite motion, signal characteristics, atmospheric and other effects, causing the receiver to actually navigate according to the parameters of the test scenario. A GNSS receiver will process the simulated signals in exactly the same way as it would those from actual GNSS satellites.

A GNSS simulator provides a superior alternative for testing, compared to using actual GNSS signals in a live environment. Unlike live testing, testing with simulators provides full control of the simulated satellite signals and the simulated environmental conditions. With a GNSS simulator, testers can easily generate and run many different test scenarios for different kinds of tests, with complete control over:

• **Date, time, and location.** Simulators generate GNSS constellation signals for any location and time. Scenarios for any location around the world or in space, with different times in the past, present, or future, can all be tested without leaving the laboratory.

• **Vehicle motion.** Simulators model the motion of the vehicles containing GNSS receivers, such as aircraft, ships, spacecraft or land vehicles. Scenarios with vehicle dynamics, for different routes and trajectories anywhere in the world, can all be tested without actually moving the equipment being tested.

• **Environmental conditions.** Simulators model effects that impact GNSS receiver performance, such as atmospheric conditions, obscuration, multipath reflections, antenna characteristics, and interference signals. Various combinations and levels of these effects can all be tested in the same controlled laboratory environment.

• **Signal errors and inaccuracies.** Simulators provide control over the content and characteristics of the GNSS constellation signals. Tests can be run to determine how equipment would perform if various GNSS constellation signal errors occurred.

Why simulate?

If we consider a fully-operational GNSS, such as GPS, it is very easy to assume that to test a receiver you would simply connect it to a suitable antenna, put the antenna out of the nearest window, or on the roof of a vehicle or building and check that the receiver can locate, track and navigate on the GNSS signals received. To some extent, this assumption would be acceptable. This method – which will herein be referred to as 'Live Sky' - would indeed verify that the receiver's fundamental RF and processing circuits are basically working. However, we are interested in testing, not simply checking for operation. Therefore, Live Sky should never be relied upon for anything more than a simple operational check, and should certainly not be relied upon for any testing during a product's conception – design – development – production and integration life cycle. In fact, in many cases it has been shown that it is also not to be relied upon for in-the-field testing following repair.

We will now look in some detail at the reasons behind these facts.

Knowledge

At the time of a Live Sky test, there are several unknowns. Detailed explanations of each are given in Reference **Error! Reference source not found.**. The unknowns include:

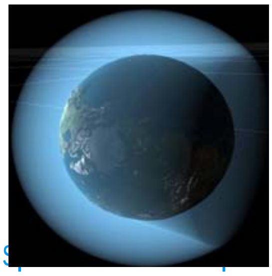
Satellite clock errors – over time, these errors should be accounted for in the navigation message and corrections broadcast, but because this message is updated infrequently, it is possible for a clock error to exist, which is not being corrected for. This will result in an incorrect pseudorange measurement, and hence an error in the receiver's computed position. Repeat tests will see a different clock behaviour, and will therefore differ in their results.

Using a satellite simulator, there are no errors on the satellite clocks, unless you wish there to be, and then they are precisely known and can be applied at known times. Also, when the test is repeated, any clock errors defined will be identical to the previous test.

Satellite orbit errors – The position of each satellite as declared in the navigation message is different to its exact physical position in orbit. This is due to several orbital errors that are caused in part by the gravitational effects of the Sun, Moon and Earth, which serve to add perturbations to the satellites position. Even though the nature of the perturbations is relatively steady and predictable (as are the satellite orbits) the orbital corrections broadcast in the navigation message will not be completely accurate, again, due to the inherent error in the prediction and estimation techniques, plus infrequent updating of the information.
With a simulator, it is possible to either remove all orbital errors and use a 'perfect' constellation, or allow fully quantifiable errors to exist in a controlled manner.

Navigation data errors – As with any data transmission system, errors occur in the data as a result of the modulation, demodulation and transmission processes. There is robustness built in as, for example with the GPS system, the last 6 bits of each word of the navigation message are parity bits, and are used for bit error detection. However, errors can still occur, and these will not be accounted for.
With a simulator, it is not possible for navigation data errors to occur, unless they are deliberately applied.

Atmospheric errors – This is a complex subject, and detail can be found in Reference **Error! Reference source not found.**. The GNSS signals have to pass through the layers of the atmosphere, which in its two main parts comprises the Ionosphere and the Troposphere. Free electrons in the ionosphere (70 to 1000km above the earth's surface) cause the modulation of a GNSS signal to be *delayed* in proportion to the electron density (its speed of propagation through the ionosphere is referred to as the group velocity). The same condition causes the RF carrier phase to be *advanced* by the same amount. (Its speed of propagation through the ionosphere is referred to as the phase velocity)
This dispersive effect of the ionosphere varies according to latitude. It is relatively stable in the temperate regions, but can fluctuate significantly in the equatorial or polar regions.



The troposphere (0 to 40km) also affects GNSS signals. Variations in pressure, temperature and humidity combine to delay the signal. Unlike the ionosphere, the troposphere is a non-dispersive medium, so it delays both the carrier and code equally. The troposphere is divided into two components; *wet* and *dry*. The dry component contributes to 90% of the delay, but can be predicted very accurately. The wet component is more difficult to predict due to large variation in atmospheric distribution (or more simply, the weather!)

The changes to the signal caused by the atmosphere directly contribute to range measurement errors, which cause the receiver to compute an incorrect position.

The effects of the atmosphere on GNSS signals are modelled, and these models are used by the receiver, together with correction parameters in the navigation data to partially correct atmospheric errors. Dual frequency receivers can go a long way to eliminating the errors, but single frequency receivers (which most commercial ones are) can only use the models available. These models are only partly successful in removing atmospheric errors, so there is always a residual error due to the atmosphere.

With a simulator, it is possible to completely disable the atmosphere, thereby removing the errors. Alternatively, errors can be applied to a known model, and are therefore fully accounted for.

Multipath – GNSS signals are line-of-sight, and can be regarded in the same way as rays of light. If a signal ray falls upon an RF-reflective surface at an angle less than the critical angle of internal reflection, it will be reflected, with some attenuation. Therefore, it is possible for a receiver to not only receive the direct line-of-sight ray, but also the reflected version. The receiver has no way of knowing which one of the two is the true LOS signal, so it uses both, and inherits the delay error present on the reflected signal. This is an illustration of a simple single reflected ray. In reality, multipath is much more complex, but the net effect is still an error in the receiver's position estimate. References **Error! Reference source not found.** and **Error! Reference source not found.** go into more detail.

With a simulator, it is possible to eliminate multipath completely, or to apply multipath to signals using various multipath models. In this way, multipath can be applied in a known, controlled manner enabling its effects on receiver performance to be accurately analyzed, and the appropriate design alterations or mitigations to be applied. With Live Sky, it is impossible to quantify the multipath conditions present at any one time, and therefore impossible to analyze and improve a receiver's performance in its presence.

Interference – GNSS signals are very weak when they reach the receivers antenna, due to the fact that they have travelled a long way from the satellites. This makes them vulnerable to interference from external sources. Interference can be deliberate (known as jamming or spoofing) or un-intentional. The vulnerability of GNSS to interference has been well documented and the discussion is beyond the scope of this document. Reference **Error! Reference source not found.** goes into much detail.

Interference not only introduces errors in a receiver's position computation, but can stop it navigating altogether. The problem this causes if interference is present (and cannot be stopped) during a Live Sky test is obvious.

With a simulator, thankfully, no such interference exists by default, but if required, it is possible to simulate it in a controlled and repeatable manner. Interference which changes as a function of the proximity of its source to the receiver can be applied using an interference simulation system such as Spirent's GSS7765.

Repeatability

When you perform testing on a GNSS receiver, and it highlights weaknesses in the design, the normal process is to make changes to the design with a view to improving it. To confirm if improvements have been made, you need to repeat the same tests *exactly*. If Live Sky is being used, it will be impossible to ensure subsequent tests are subjecting the receiver to the same conditions as the original test. The most obvious difference is the fact that time has progressed, and the constellation visible to the receiver will be completely different. These are factors that by themselves will ensure the test conditions cannot repeat. The other characteristics that will not remain fixed are atmospheric influences and satellite performance.

Therefore, Live Sky is unsuitable as a method for testing with a view to making design improvements.

With a constellation simulator, every time a test scenario is run, the signals produced are identical. The scenario will start at the same time on the same date, and the satellite positions will be identical – even down to the relative phase offsets between the different signals. In this way you can guarantee that the receiver is being stimulated with the exact same signals every time the test is run. Only this way can you fully determine any improvement (or otherwise) the design alterations have made.

Proper measurement of physical design changes is not the only reason for performing completely repeatable testing. If the results of testing are required as input to a verification or certification process, they must be reliable and un-ambiguous. For example, if two companies are building receivers for a certain critical or safety of life application, and they have to be certified to an international test standard, then the test conditions must be identical to avoid one company having an advantage over the other. The test methods used in test standards should always be designed to reduce the measurement uncertainty as far as possible to preserve the integrity of the tests.

Controllability

With any comprehensive testing, finite and accurate control of the test conditions is essential. Fine-tuning of a design or system parameter can often demand very small, closely-controlled manipulation of the test conditions. With a Live Sky test method, there is little that you have control of. With the exception of the physical location of the test antenna, there is in fact nothing else that you have any control over. You cannot wind back time, disable the atmosphere, adjust the satellite signals, errors, data, orbits – all of which are parameters you need to have complete control over.

Accuracy

A GNSS RF Constellation Simulator is a precision piece of test equipment and if properly maintained, its performance is accurately specified and controlled. The fidelity of a simulator's signals is much better than the signals from a real GNSS system, which not only allows advanced testing of a receiver's true 'laboratory' performance, but means that signal noise contributions due to the simulator are well below the level of thermal noise, and therefore will not contribute any noise errors to the test.

Two parameters closely related to accuracy are quality and reliability. The precision engineering employed in the simulator's design and construction, and the quality control processes governing these disciplines ensure that the equipment gives reliable service for many years.

Capability

In practically all known applications where vehicle motion is present, a simulator will far exceed the dynamics required to simulate that motion. It is therefore possible to test a receiver well beyond the boundaries of its intended operational environment – something not possible by any other means. This allows the true maximum performance of the receiver to be characterized and accurately de-rated for the intended application.

Commercial viability

No project survives without a sound business case. Those responsible for managing projects and setting budgets will have to take this into account. It is often wrongly assumed that simulation only saves money over real field trials for applications involving high-dynamics on sophisticated platforms. For example, it is very obvious that there is no way a space-grade receiver can be flown in orbit purely in order to test how well it works, but what is often not so obvious is the fact that simulation can prove to be more cost effective for much less sophisticated applications. A leading European automotive manufacturer calculated that the total cost of performing a real drive test is in the order of £5k per day. Notwithstanding the technical issues with real-world tests already discussed, the financial cost-benefits alone are enough to demonstrate the viability of simulation. A few months of drive testing will pay for a simulator, and in many cases makes its choice over real field trials academic.

The methodology of simulation

So far, we have discussed the reasons for selecting simulation as the preferred GNSS test method. In this section we will look at the methodology of simulation, examples of different simulators and how they may be used for testing in different applications.

To re-cap we remember that an RF Constellation Simulator reproduces the environment of a GNSS receiver on a dynamic platform by modelling vehicle and satellite motion, signal characteristics, atmospheric and other effects, causing the receiver to navigate on the simulator's RF signal, according to the parameters of the test scenario. What a simulator is not is a magic box which reproduces the real world in its entirety. However, far from being a limitation, this is an important benefit. In the same way that an RF design engineer would not use a random noise generator when he really needs a controlled and quantified test signal, a GNSS receiver tester would not use a random real-world signal-reproducing device when he really needs a controllable and repeatable simulated GNSS test signal.

A receiver's performance will vary depending on the severity of the errors and effects applied to the RF signal. Figure 2 shows a representation of the signal flow through a typical simulator, with the various effects being added, until the final RF output, from which the complex resultant RF signal is output to the receiver under test. This principle applies to all simulators, with the number of effects depending on the capability of the simulator, and its intended application.

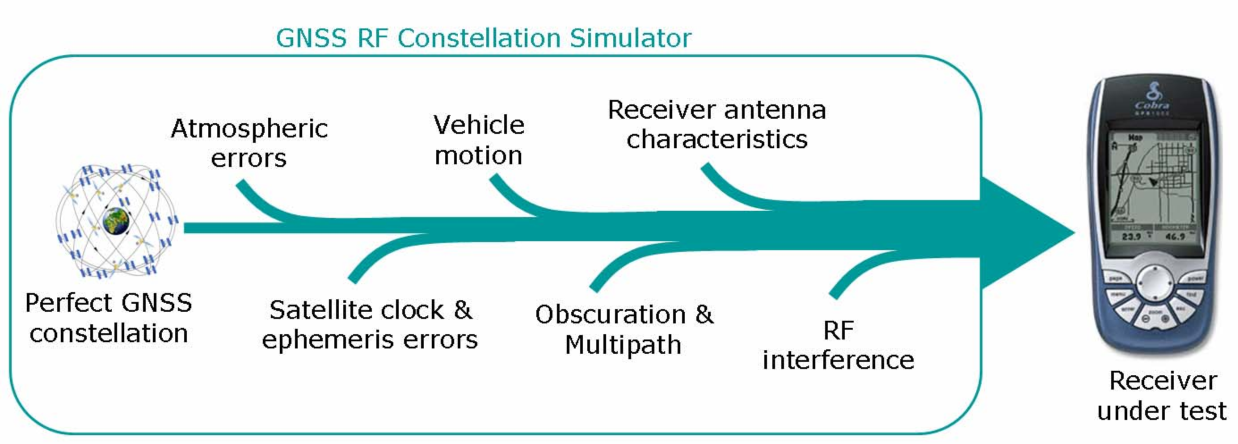


Figure 1 Simulation signal flow

Figure 2 shows a typical set-up in more detail. A Spirent GSS6700 simulator is pictured. Position Velocity and Time data (typically in NMEA 0183 format) from the receiver can be fed back to the simulator control software and compared with the simulated 'truth' data. This will give a very accurate measure of the receiver's performance against the known characteristics of the simulator's signal.

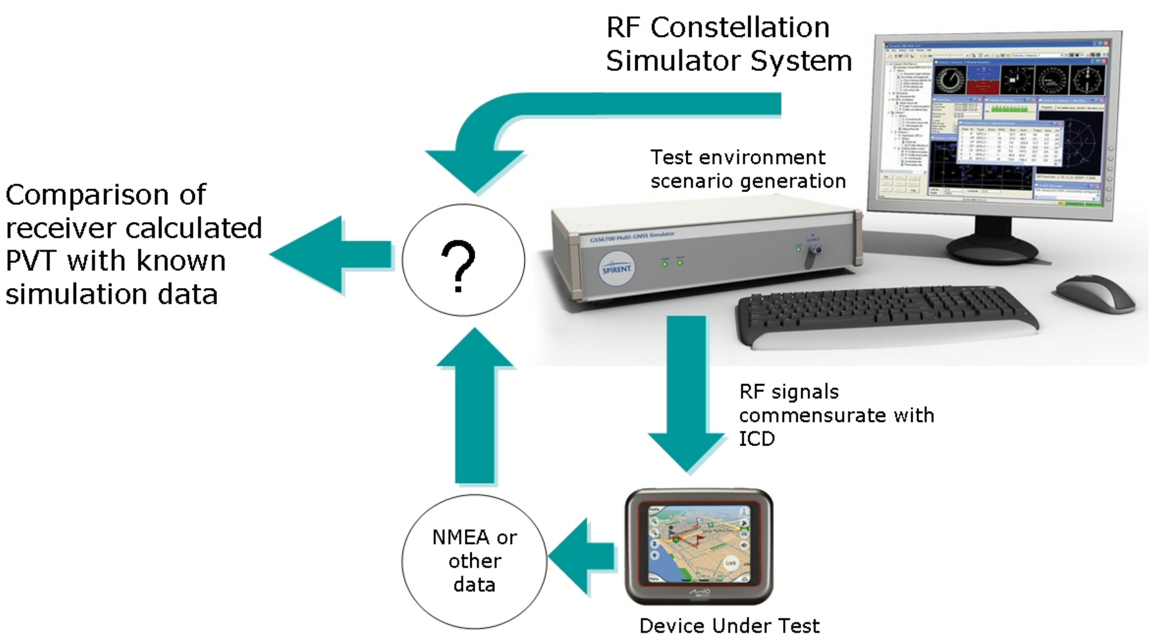


Figure 2 Simulation test set-up

Performing a simulator test

Setting up and running a receiver test using a simulator is relatively straight forward. It can be summarised in two stages:

- Definition
- Run-time

The Definition stage is where the required test parameters are set-up using the simulator control software. At this stage you need to:

- Understand the application for the receiver to be tested, and the operating environment
- Determine the tests you need to perform
- Define the test scenario with the appropriate effects
- Understand how to connect the receiver to the simulator in order to maintain the appropriate RF conditions

The Run-time stage is where the scenario is running and the simulator hardware is producing the requisite RF signal. At this stage you need to:

- Observe the receiver under test and manipulate the simulator as appropriate
- Analyse the receiver performance. This can be undertaken either in real-time or by post-test analysis of recorded data. Access to the simulation data (the data used to create the test signal) can be gained in various ways from data-streaming to logging to a file. This data can then be used to compare the receiver's performance with the 'truth' simulation data.

Spirent GNSS Simulators

Spirent is the industry leader for GNSS simulator products. Spirent offers several different models of GNSS simulators that support a variety of different applications and cover the full spectrum of civilian and military GNSS testing needs. Spirent products range from basic single-channel simulators, suitable for simple production testing, through multi-channel, multi-constellation simulators, suitable for the most demanding research and engineering applications. For more comprehensive testing, Spirent also offers products that simulate additional system elements simultaneously with the GNSS constellation signals, such as inertial sensors, various automotive sensors, Assisted GPS (A-GPS) data, SBAS and GBAS augmentation system signals, and interference signals.

With almost 25 years of GNSS simulator experience, Spirent provides GNSS simulators with unparalleled performance, features and comprehensive support.

Spirent's Multi-GNSS simulation platforms

Spirent offers a wide range of test systems and capabilities to meet your Multi-GNSS test needs. Our Multi-GNSS systems are designed with future development in mind and are expandable to address tomorrow's test requirements as well as todays. Whether you are undertaking R&D performance testing, integrating devices into your product line, verifying performance or assessing manufacture of Multi-GNSS devices, Spirent has a Multi-GNSS test system available today to match your needs.

The **GSS8000** Multi-GNSS Constellation Simulator; Up to three RF carriers, selected from a range of constellations and signals (GPS, Galileo, GLONASS and Quazi Zenith Satellite System), can be accommodated in a single signal generator chassis. This enables multiple signals from a single constellation or hybrid systems with signals from multiple constellations to be tested. The architecture supports future Compass signals.

The **GSS6700** Multi-GNSS Simulation System offers up to 36 channels of combined GPS/SBAS, GLONASS and Galileo L1 signals from a single chassis, 12 channels for each constellation. The GSS6700 is available with one, two or three constellations enabled. Different software capabilities and flexibility are available to suit different test needs. For existing Spirent STR4500 or GSS6560 customers who today test GPS/SBAS L1 only, the GSS6700 offers the ability to simulate not only GPS/SBAS but also GLONASS and Galileo.

The **GSS6300** Multi-GNSS Signal Generator is designed specifically for production test applications where a single channel is required for controlled GNSS testing. The GSS6300 can generate a single, combined GPS/SBAS, GLONASS and Galileo signal to enable testing of GPS only or Multi-GNSS devices in a production environment. For existing Spirent GSS6100 customers, the GSS6300 has an identical capability, form factor and interfaces when specified in GPS/SBAS configuration. In addition, the GSS6300 offers the benefit of on-site (even in-rack) upgradability to add GLONASS and Galileo generation capability concurrently with GPS/SBAS.

Spirent GSS8000 Multi-GNSS Constellation Simulator

Spirent GSS6700 Multi-GNSS Constellation system

Spirent GSS6300 Multi-GNSS Signal generator

For more information on GNSS applications, GNSS receiver testing and the benefits that GNSS simulation can offer you, visit www.spirent.com/positioning

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