

Testing GNSS for Railway Applications

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1. Introduction

The use of Global Navigation Satellite Systems (GNSS) in the Railway industry is increasing rapidly. GPS technology is already being used in several areas, from Fleet Management to Passenger Information Services. In some countries, GNSS navigation is being considered for use in safety of life applications such as:

- PTC (Positive Train Control) on low-density lines, as a supplement, or even a replacement for conventional line-side signalling and control systems.
- Automatic door operation
- Train integrity and separation control
- On Train monitoring & Recording (OTMR)
- Train Protection & Warning Systems (TPWS)
- Off-train infrastructure protection (level crossing operation, End of line stop limits)

Two important characteristics for GNSS operating in the railway environment are **integrity** and **availability**, both of the GNSS and of the user equipment. An on-train navigation or control system which is to be relied on for safety, must operate reliably and with integrity. In addition, the availability and integrity of the GNSS itself must be quantified and understood. Suitable robustness must be built in, whether in the form of augmentations or other complimentary navigation sensor inputs. For these and other reasons, proper testing is not only desirable, it is essential, especially if the test results provide an input to certification of GNSS systems for safety-critical applications.

This Application Note is for designers, developers, integrators and testers of GNSS receivers or systems, who need to ensure their products will perform in the intended environment. It also provides key information regarding the importance of proper testing for those responsible for developing test standards for certification of GNSS equipment in the railway sector.

Spirent recommends you have a basic understanding of satellite navigation principles and awareness of RF simulation as a test method is desirable.

2. The Environment

The railway environment is a varied one. In the application of GNSS navigation, it presents many different conditions. Some of these conditions affect the way navigation works, and in some cases severely limits or even prevents its use. The primary issue concerns the reception of the line-of-sight RF signals from the satellites. The amount the reception of these signals is degraded directly affects the availability of the signal and the degree of navigational error experienced by the GNSS user.



The main characteristics in a railway environment that are likely to affect the ability of a given GNSS receiver to receive, process and resolve the satellite signals - include (among others):

Obscuration

The line-of-sight satellite signal path is blocked by physical obstructions such as bridges, tunnels, station roofs and canopies, steep-sided cuttings, trees, surrounding geographical features, signal gantries, Overhead Line Equipment, trackside buildings, parts of the railway vehicle, passing or adjacent vehicles etc.



Figure 1 The receiver's view off all but the highest-elevation satellites is severely restricted by deep cuttings

Multipath

The receiver sees a repeat(s) of the direct line-of-sight signal, due to the signal reflecting off the obstructions listed above. This is complicated by the movement of the train and satellites relative to these objects and each other, which results in multipath signals with dynamically changing phase and amplitude characteristics. The combined complex effect of these changes is called often referred to as fading.



Figure 2 Overall roofs such as this at London's St. Pancras station not only attenuate satellite signals, but the complex metallic frames that form the structure can also cause multipath problems

Interference

GNSS signals travel tens of thousands of kilometres from the satellites and are extremely low in power (approximately -120dBm nominal) when they reach the receiver. This makes them particularly vulnerable to interference from other sources. These sources could include: Overhead Line Equipment,

or third-rail power systems, on-train electrical systems: generators, motors etc. Other radio communication systems, both within the railway operation and external (TV, mobile phone transmitters) and possibly intentional or un-intentional jamming of the GNSS signals.

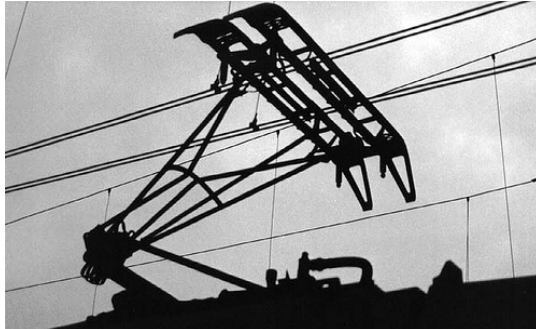


Figure 3 Locomotive pantographs can cause high-strength electro magnetic interference, especially when arcing occurs. Careful positioning of GNSS antennas is important

3. Using the right system

Currently, GPS is the only fully-operational GNSS system that can be effectively used for navigation. GPS, when working with augmentations such as SBAS and RTCM Differential Corrections, or coupled with an Inertial Navigation System (INS), can provide fairly repeatable and accurate navigation. However, there are limitations when it comes to the guarantee of service, and for many applications the lack of integrity presents a problem, especially where safety critical systems are relying on continuous availability and accuracy. Future GNSS systems, such as Galileo, will provide (for a fee) signals and services that are guaranteed to operate within a certain specified performance. At the time of writing, there is much discussion on the certification of these services for use in different applications. Safety-critical operations in Railway applications are considered to be in the 'top-four' sectors where high-integrity terrestrial navigation is demanded. The other sectors are Maritime, Aviation and Road.

The other aspect requiring careful consideration is that of the receiving equipment. There are many types of GNSS receiving equipment available from different manufacturers, and with these many types come varying levels of performance and suitability for different applications. It is important to ensure the 'system' (receiver, antenna, cabling and interfaces) being used is the best suited and most optimised for the particular application.

For a typical railway environment, the considerations that should be made when selecting a GNSS system could include:

Performance – How well does the system need to cope with:-

- Availability of the signal due to the environment?
- Integrity of the signal due to the environment?
- The characteristics highlighted in 1?

Standalone or augmented – Is the system independent of other navigational aids, or does it need to be used as part of another navigation system? (DGPS corrections or inertial sensor inputs for example). Does it require WAAS or EGNOS capability?

System data outputs – what format does the position-velocity-time information need to be to be used by other systems, is there compatibility between the interfaces?

Maximum separation between antenna and receiver – is the receiver likely to be located far from the receiving antenna? If so, is the signal loss acceptable? Is the coaxial cable suitable?

Robustness – will the equipment stand up to the environmental conditions it will be subjected to? – Vibration, heat, dust, rain ingress etc.

4. Testing is essential

With so many variable conditions in which the GNSS system has to work, it is essential that comprehensive testing is carried out. This gives a measure of how the system will perform when in operation, but the scope of testing is not limited to this. Testing can be used in a number of ways:

- Performance assessment both in nominal and adversarial conditions
- System testing from R&D to verification, production and deployment
- System or unit calibration
- System verification and certification to prescribed standards
- Repair and fault diagnosis for equipment in the field

Testing is important, but more important is the right kind of testing – that which is relevant to the particular application. GNSS system manufacturers will no doubt test their products to ensure they function generically, but may not test them thoroughly for specific applications.

4.1. Test methodologies

Perhaps the most obvious way to test a GNSS system is to take it into the environment in which it will be used and try it out. Often called 'Live-Sky' or 'Real-World' testing. In theory this sounds the most effective way. However, there are many constraints that rule out the feasibility of this approach. Live sky can never be more than a 'quick check' and should certainly never be adopted as a reliable test method. From the perspective of a railway application - the following constraints may apply:

- **Cost** – Running test trains is very expensive. The capital cost of non revenue-earning rolling stock, train crews (driver etc) Running costs (fuel, maintenance, hire of equipment, hire of test tracks or paths on ordinary lines). While R&D work may be funded at technology concept stage, equipment manufacturers are unlikely to be able to afford this method on an ongoing basis.

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- **Access** – It is often difficult to take possession of a section of busy railway line for the purpose of running non revenue-earning test trains. Permanent Way possessions are often restricted to night hours or weekends when there is less traffic. There is often a lot of pre-planning required that involves other departments or even companies within the railway infrastructure (signalling staff for example) again; cost is an issue – access charges applied by the network operator is another example.
 - **Regulations** – There are a plethora of regulations that make carrying out tests difficult. Approvals from the relevant Vehicle Acceptance Bodies (VABs) are necessary for fitment of test equipment to the railway vehicle. If service rolling-stock is used then access to the equipment while a train is in service may be difficult. The need to use approved personnel to fit the equipment in a way that will not compromise safety may have to be considered.
 - **Repeatability of the tests** – It may only be possible to run a test once, and even if repeat tests were possible, the conditions will never be the same twice, not least in respect of the GNSS signals, where the satellite positions (and orbits) will be different, the atmospheric conditions will be different etc. With regard to the railway vehicle, it is impossible to run the train in exactly the same way (speed, wheel-slips, braking conditions will always vary)
 - **Integrity of the tests** – Live sky testing is, in reality, limited in its worthiness to no more than a quick confidence check. Testing in relation to qualification, type-approval and certification activities certainly cannot rely on this kind of testing. These activities demand levels of accuracy, repeatability and accountability that can only be offered by a test methodology based on precision test equipment in a well-controlled environment.

The test methodology most suitable in these circumstances is **RF Simulation**.

Simulation immediately solves the constraints listed above, and provides an effective alternative to many others. Simulation that involves stimulating the GNSS receiver or system with actual RF signals is the most effective way of testing. GNSS simulators are fully capable of accurate replication of the signals-in-space through modelling of the satellite constellation motion and that of the receiver. The RF navigation signals generated by a GNSS simulator are also fully controllable: for example, satellites can be switched on and off, power varied and if required, known, controlled errors introduced. This allows receiver deficiencies to be quickly isolated. Simulation has a number of distinct advantages over other methods, some of the more obvious benefits are:

- **Repeatability** – The same tests under the same conditions can be repeated again and again – something that can never be achieved in the real-world test environment. With simulation, you have complete knowledge of the ‘truth data’ i.e. the bit-by-bit parameters being used to generate the RF signals. With this, you are therefore able to know exactly what you are stimulating your receiver with. This level of repeatability is essential for meaningful and reliable testing of GNSS equipment for railway applications.

- **Time and Cost effectiveness** – As we have seen already, the cost of conducting real field tests, in a timely and efficient manner with expensive assets on an increasingly crowded railway infrastructure is high, but is greatly reduced if a simulation test methodology is used. In comparison, the capital investment in a simulation system is in fact quite low when compared to the real-world approach, and the initial investment is soon recovered in cost savings. Often, funding for field trials in the early stages of a research project is available through official programmes. However, such funding is usually limited and normally disappears once the project gains commercial momentum. Test campaigns are then influenced by normal business processes, which will seek to reduce costs.
- **Simplification** – In the real-world, the GNSS receiver or system is experiencing many error-inducing effects simultaneously, so it is very difficult to identify which phenomenon may be causing the system performance to be degraded. With Simulation you can apply the effects in a precisely controlled, ordered and accountable way, greatly increasing ease of characterisation of the GNSS system under test. A common misconception is to assume you need to replicate the real-world as closely as possible. This would in actual fact reduce the effectiveness of the testing for the reasons already given. Controlled representation is in fact the method required.
- **Pushing the limits** – In the Real-World, you have no control over the satellites or signals, no control over the signal conditioners be they atmosphere, multipath, obscuration, satellite errors, data corruption, and no way of running the test train at higher than permitted line speeds to enable the dynamic performance of the receiver or system to be tested beyond its normal operating limits. As such you have no way of building in any system design margins, be they redundancy, safety or reliability. With Simulation, you are able to control any parameter you wish. You are able to remove the atmosphere effects, add or remove Multipath and obscuration or test the receiver under much more controlled dynamic motion than is possible in the real-world.
- **The only option** – In some cases, RF simulation is the *only* option for testing because the real GNSS signals do not yet exist. Galileo is an example today, as GPS was in the early 1990s before full operational status was achieved. Systems and equipment will need to be developed ahead of the operational of the actual GNSS system, requiring RF simulators capable of producing all the specified signals.

These are just some of the benefits that can be obtained by using Simulation to test in a way that either cannot be done, or can only be done with unacceptable measurement uncertainty, timescales or cost in the real-world.

Table 1 attempts to provide a summary comparison between Real-World and Laboratory test.

Real World Test	Laboratory Test
Actual unquantifiable Environment	Modelled, representative known environments
Test in nominal use conditions	Test nominal and extreme, off-design performance
Different conditions for each test	Exactly repeatable
Often takes time and costs too much	Generally more efficient
Not reliable for formal certification	Quantifiable and certifiable

Table 1 Real-World vs Laboratory simulation summary

5. Test Standards

The use of GPS and its limitations as a standalone technology in various safely-critical applications has been well documented. Where it has been deemed acceptable, comprehensive evaluation of its suitability and performance has taken place. The result of this has been the issuing of directives by various 'responsible authorities' that set out the Minimum Operational Performance Specifications (MOPS) that navigation equipment being deployed in the respective applications must meet.

International standards organisations have then taken these MOPS and developed appropriate test standards to allow equipment to be certified for use against the requirements.

Given the facts already highlighted in this Application Note concerning test methodologies and their suitability, it is important that simulation as a test methodology is understood and adopted in these test standards. This not only requires an awareness of the philosophy of laboratory simulation, but an understanding of the test methods and their development, and how to best implement them in the test descriptions within the standards.

The development of Galileo will naturally drive the need for new test standards, and those responsible for their development will need to understand simulation as a test methodology. Some test standards are already well advanced, and take full advantage of RF simulation in their test procedures. An example from the maritime sector is IEC 61108-3 *Galileo – Receiver equipment – Performance requirements, methods of testing and required test results*. All the navigation related tests are performed using an RF simulator. Equipment manufacturers are able to base their development on simulator testing using the same test methodologies that are employed in the test standards, which ensures their designs are much more likely to meet the requirements.

6. Example test

This chapter describes an example test scenario created using Spirent's **SimGEN for Windows**[®] software, which is designed to test a GNSS receiver in a railway-like RF signal environment. The test scenario enables the characteristics already described in this Application Note to be applied to a



navigation system.

SimGEN is Spirent's powerful scenario creation and simulation control software. It is designed to operate with a number of simulator hardware platforms. One such simulator is called the GSS6560.

The GSS6560 is a 12 independent channel (satellite) GPS L1 C/A code simulator, particularly suited to the commercial environment. It has complete scenario generation capability using the SimGEN software that offers the user class leading accuracy; fidelity and reliability; full user control of GPS constellation, errors and atmospheric effects; control of vehicle motion, antenna modelling. It also supports Space Based Augmentation System (SBAS) signals (WAAS/EGNOS/MSAS) as standard.

6.1. Typical test set-up

Figure 4 shows a typical receiver test set-up in its basic form. The simulator shown in this example is a GSS6560.

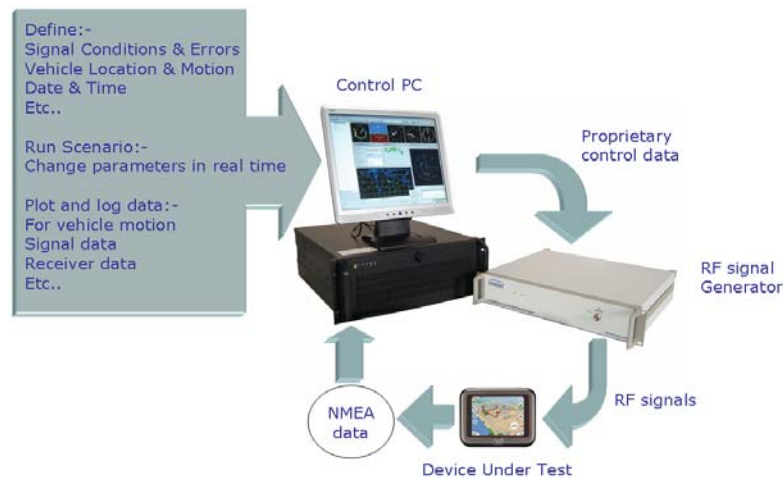
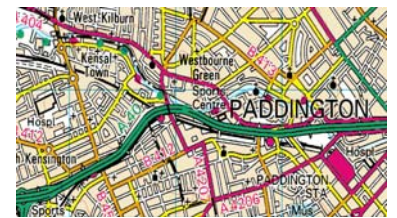


Figure 4 Typical test set-up

6.2. Scenario description

This scenario example simulates a non-stop express train journey along the Great Western Main Line from Reading Station, Berkshire to Paddington Station, West London, UK. The scenario begins on 28th Feb 2007 at 1200. The motion trajectory follows the route of the railway as defined by the Ordnance Survey 1:50,000 scale map for South East England (region 2).



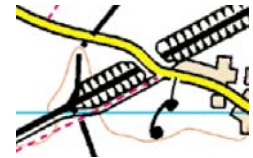
The speed profile involves a 120 second stationary period at Reading station, followed by a steady acceleration to near-maximum line speed of 123mph followed by a deceleration at the end of the scenario on arrival at London Paddington station.

The scenario demonstrates how navigation degrading effects can be applied without the need to venture into the real environment to collect data, another key benefit of simulation.

Terrain effects

The following local terrain effects are applied. These effects simulate physical obstructions to the satellite signals in specific locations as observed from the Ordnance Survey map.

Cuttings are simulated using SimGEN’s Vertical Planes feature. Vertical Planes are simulated at 30m Left & Right distance relative to the vehicle, height 20m, Time of occurrence and duration are varied, and determined from the map.



The vertical Planes block the LOS signal path from the satellite to the receiver.

SimGEN’s Vertical Plane file editor is shown in Figure 5. As can be seen, a list of time-ordered planes is displayed in a list on the left side, the Vertical Plane characteristics are applied using the fields on the right.

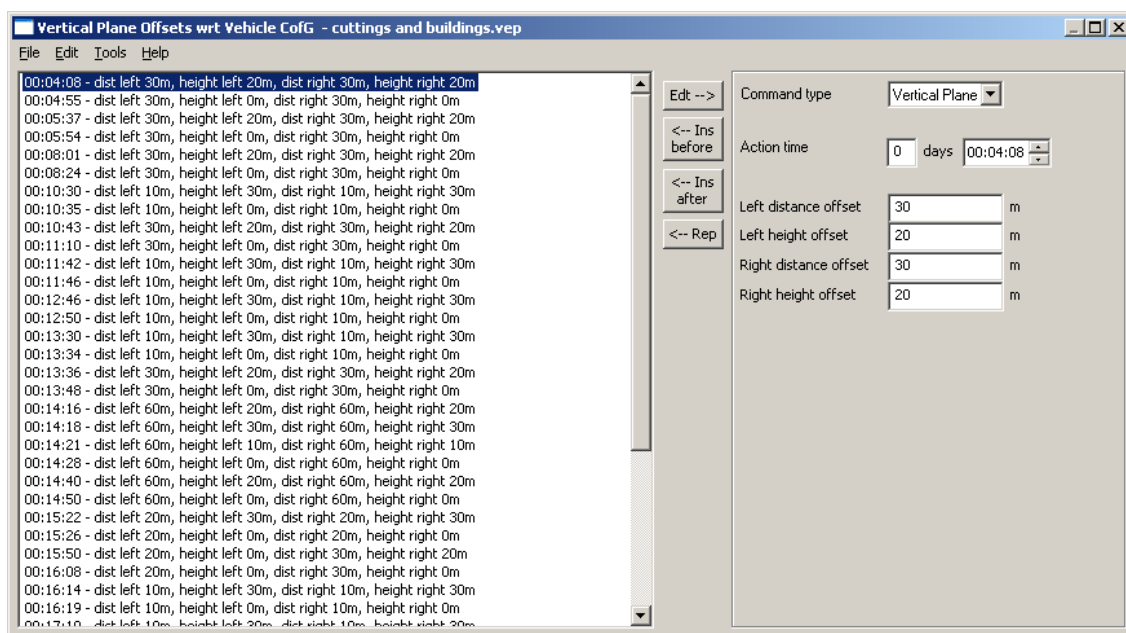


Figure 5 SimGEN's Vertical PLane editor



Stations are also simulated using Vertical Planes at 10m L & R distance, height 30m, duration – 5 seconds assumed for all stations. As with the cuttings, the location of each station is determined from the map.

Line-side buildings are simulated using Vertical Planes at varying distances, heights and durations determined from the map.

Bridges are simulated by switching off all satellites for 1 second when they occur, as observed from the map

There is one tunnel (at Ealing, 17 min 42 sec) simulated by switching off all satellites for 7 seconds. SimGEN’s User Action file is used to define the off an on times for the satellites. For each bridge the satellites are switched off and back



on again. The User Action File editor is shown in Figure 6. As with the Vertical Plane editor, a list of action is displayed on the left, and the command entry is shown on the right.

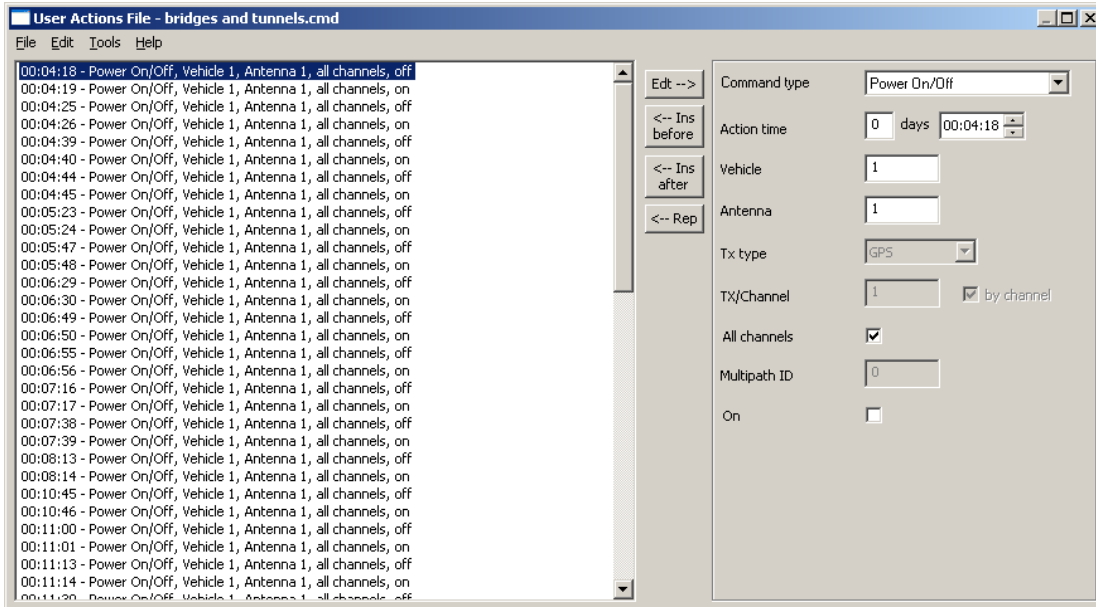


Figure 6 SimGEN's User Action file editor

Terrain Obscuration which is not due to stations, bridges or cuttings, but due to general urban terrain (mainly multi-storey buildings) is applied using SimGEN's Terrain Obscuration file editor. The general surrounding terrain becomes more close-urban after Southall (16 min 14 sec) so at this point Urban-Canyon Omni directional obscuration is applied (to the end of the scenario). The Terrain Obscuration file editor is shown in Figure 7

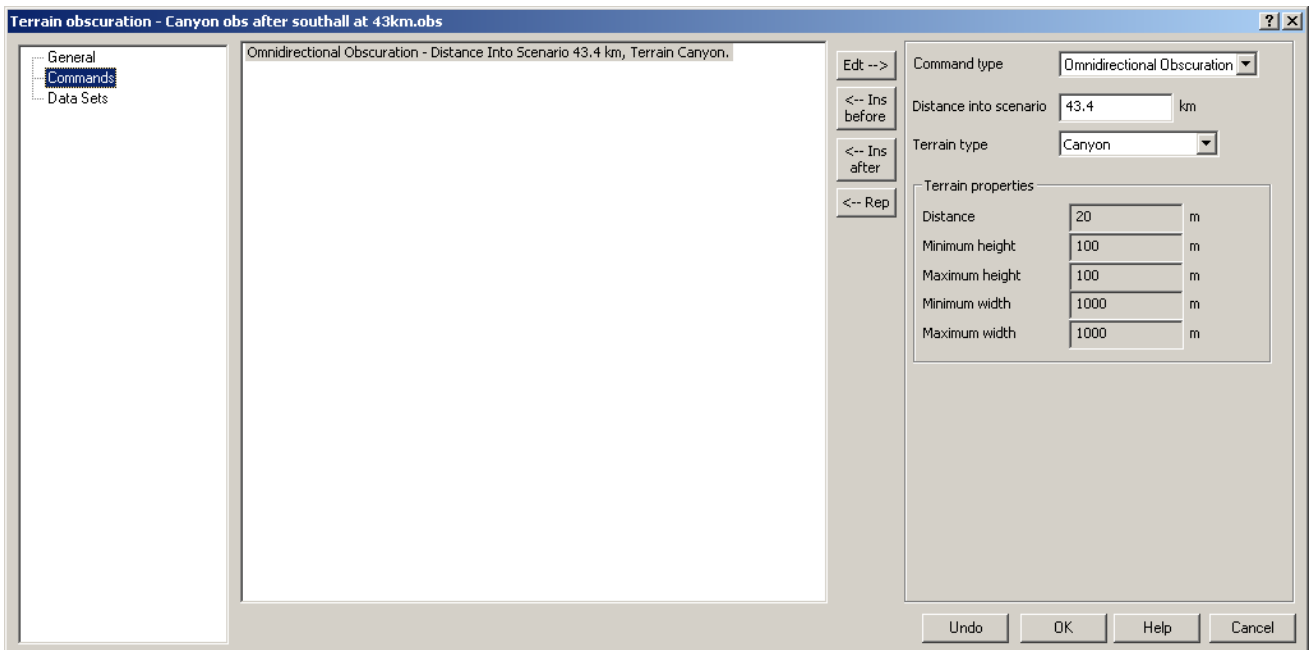


Figure 7 SimGEN's Terrain Obscuration editor

On-train obscuration is applied via SimGEN's Antenna Pattern Editor. The simulated position is on the roof of the train, so the antenna pattern provides an un-obstructed view of the sky above zero degrees elevation, and blocks all signals below that elevation, representing the obscuration due to the train's roof. The Antenna Pattern Editor is shown in Figure 8. It is a 2-D display of the antenna's attenuation characteristics over all angles of elevation and azimuth. Each cell represents one degree of elevation by one degree of azimuth.



Figure 8 SimGEN's Antenna Pattern Editor

A three-dimensional view of the antenna pattern is shown in Figure 9. As can be seen, all signals below zero degrees elevation will be obscured.

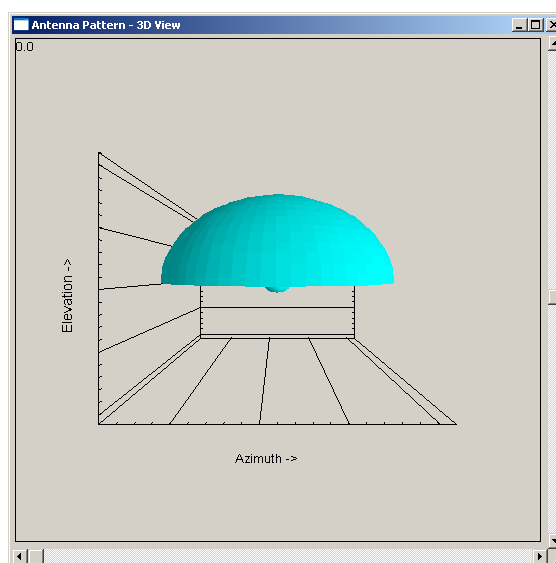


Figure 9 3-D Antenna Pattern view

At the destination (Paddington Station) there is an overall roof (iron girders and glass panels). The effect of this is simulated by a 6dB reduction in power on all satellites. This is achieved using the User Action File shown in Figure 6.

6.3. Alternative methods

The example described in this Application note is just one of the possible methods that can be used to create the simulator test. This particular test was developed without the need to leave the laboratory at all. In some cases it may be desirable to use real data. This real data might be actual route trajectory data based on receiver NMEA data, or obscuration profiling information based on actual video capture techniques whereby the 'skyline' around the train is determined from images, which are then converted into obscuration elevation angles along the route thereby determining satellite visibility. Examples of this type of data capture include the PREDISSAT tool developed by the French National Institute for Transport and Safety Research (INRETS) See Reference 1.

It is possible, with simple manipulation to translate such obscuration data into commands that SimGEN will then execute to control satellite visibility. Figure 10 illustrates the process.

Huge benefits can be gained from this kind of approach. The main benefit is that only one test run is required to capture the data – all subsequent testing being carried out on the simulator in the lab, saving significant time and money, and providing repeatable tests for evaluation of subsequent design iterations.

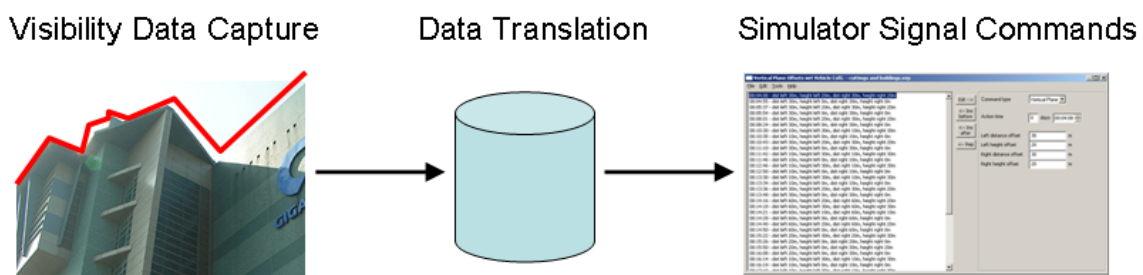


Figure 10 Capture to simulation process

7. Pushing the boundaries

The methodology discussed in this Application Note goes a long way towards testing a GNSS system in a railway-like environment, without the expense or time involved in collecting real data. However, with the GNSS simulator it is possible to add many more characteristics to the simulated signal to further extend the test complexity, once the initial fundamental performance characteristics of the GNSS equipment are well understood.

The scope of the SimGEN test scenario could easily be extended to include:

Multipath simulation

SimGEN has several ways of applying different multipath signals in a controlled way. Multipath can be applied in real time while the scenario is running or via pre-scripted commands. Various types of

multipath can be applied and characteristics such as code and carrier phase and attenuation of the signal can be varied.

Interference Simulation

Controlled interference signals can be added to the GNSS test signals using Spirent's GSS7765 system. The GSS7765 allows interference with different signal modulation and power characteristics to be applied. Interference can also be modelled with respect to the proximity of the interferer source and the receiver position such that the power level of the interfering signal varies appropriately.

Navigation system errors outside of the receiver environment (system and satellite errors)

Imperfections in the actual GNSS system were eluded to in the abstract at the beginning of this paper, and these exist in all GNSS systems. A receiver needs to be able to deal with such imperfections, even if only to detect and warn of a problem. SimGEN has several ways of adding pre and post parity-checked errors to the navigation message broadcast by the simulated satellites, satellite clock drift and errors, as well as orbit and ephemeris errors, both nav-data-declared and un-declared. These can be scripted to occur at specific times, and receiver behaviour observed for cause and effect appropriately.

Atmospheric conditions (RF signal delay and fading due to the ionosphere and troposphere)

One of the largest randomly varying source errors in any standalone GNSS system comes from the effect of the atmosphere on GNSS signals. These effects can be modelled in SimGEN to varying degrees by defining the ionospheric and tropospheric models

Simulation of augmentation systems

SBAS (WAAS, EGNOS, MSAS) is fully supported by SimGEN and can be added into the test scenario. SBAS enabled receivers can then be tested fully.

RTCM differential corrections (DGPS) commensurate with the simulated signal can also be output from SimGEN, and receivers with DGPS data inputs can then be tested

8. Next Steps

Spirent Communications PLC is the world leader in providing GNSS test solutions. Our experience and pedigree spans more than 20 years, and our current range of RF Constellation Simulation systems benefit fully from this heritage. Our solutions and expertise are therefore invaluable to anyone with a GNSS test need.

Spirent offers a comprehensive range of RF satellite signal generators and full-constellation RF simulators for GPS, Galileo and GLONASS GNSS systems, and we can advise on the most suitable approach you should take to facilitate the testing required for your application.

Spirent is always keen to work with organisations to help them develop their products and services, and to help develop the use of GNSS in new and emerging markets.

Examples of where we could work in such a way include:

- Evaluation of real-world data with a view to using it to create scenarios for the simulator.

- Comparison of field test results with simulated results.
- Provide expertise to support standards and certification development for GNSS railway applications.

We welcome dialogue with interested parties. Please contact us if you are interested in such cooperation.

9. Referenced documents

1. Satellite propagation analysis in a masking environment for GNSS applications [J. Marais, INRETS-LEOST]

10. Further information

Spirent's Test Services Team is dedicated to providing you with information and test solutions to help you with your testing needs, and to that end, we are actively producing Application Notes and Test Methodologies on a wide variety of GNSS test subjects. Please visit www.spirent.com/positioning, or www.spirent.com and click the Satellite Navigation link regularly to find the latest articles, or ask your Spirent Sales representative for more information.

Spirent customers who have a current SimSUPPORT agreement can also benefit from an extended range of Test Methodologies, which can be found by logging into the Support website:

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