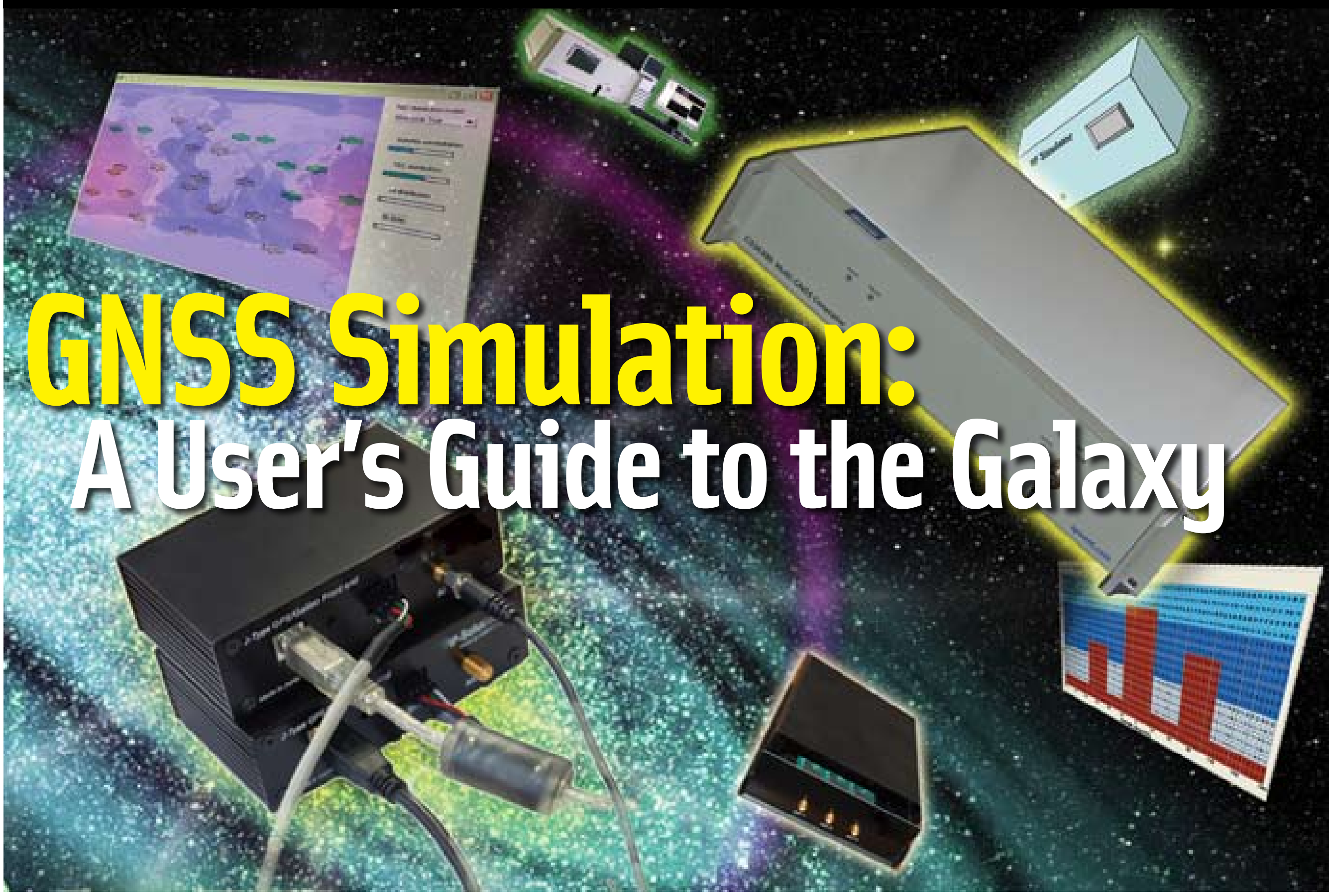

GNSS Simulation: A User's Guide to the Galaxy

This article concludes our series about the use of simulators and simulation techniques in developing GNSS receivers. Part 3 examines various simulator designs and whether the specifications of any given simulator equpment is suitable for a particular test.

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In the first article in this series (*Inside GNSS*, July/August, 2010) we looked at the range of tasks that require GNSS signal simulation during design, manufacturing, certification, and maintainence of GNSS equipment. The second installment (*Inside GNSS*, September/October, 2010) described a range of simulation solutions.

In this final article, we try to find a simulation solution that best suits a particular task.

Live Satellites Versus Simulation

Until this point in the series we haven't really discussed the possibility of using live satellites for testing. The main disadvantage in using live satellites is that a user has much less control over the test environment.

With live satellite testing the user can only to some extent determine the GNSS user equipment's antenna location and operating environment and has no control over the signal parameters themselves. Therefore, using a live satellite type of testing at R&D, design, certification, and maintenance stages is much less deterministic than use of an RF simulator, and even during manufacturing and QA testing the latter approach has the advantage.

Let's look, for example, at a few tests that we may wish to do during a receiver design process and see if they can be done using live satellites. We used our software receiver to conduct these tests in combination with a high-end RF simulator for GPS and GLONASS. We also have conducted a number of tests for Galileo, as far as Galileo is supported by the receiver.

Figure 1 shows a screen shot of the total satellite constellation that we simulated during the test.

Our tests mirrored a few general tests and may be described as follows:

1. After receiver tracking loops are designed, we would need to check if they deliver correct observations, such as code phase, carrier phase, Doppler, and carrier-to-noise ratio (C/N_0). Using a simulator we know the true observations and directly compare them with those measured epoch by epoch.

This test may be possible to do with live satellites, but with much greater effort and less usable results. Such a test would require us to survey the antenna position in advance, collect the predicted ephemerides, and calculate a predicted range to a satellite and Doppler shift.

This procedure, however, would not guarantee definitive results. For instance, the satellite orbits can be predicted very precisely to satisfy needs of such tests, but the satellite clock predictions may not be so precise and reliable. Consequently, those satellite clock errors will, in effect, show up as incorrectly predicted orbits. Also, separating the receiver hardware–related measurement biases from the satellite hardware and signal propagation–related measurement biases is difficult with this approach.

2. When we are working on a receiver's navigation processor, we may wish to optimize the equipment's ionospheric and tropospheric error compensation. In the corresponding test we can toggle the ionospheric and tropospheric errors in a simulator, and the user can directly assess the accuracy and performance of the ionospheric and tropospheric correction algorithms implemented in the receiver.
3. While debugging a navigation processor, we also can compare an encoded navigation message with one decoded by the receiver side by side to ensure the correctness of our decoding algorithm.
4. We should be also interested in measuring receiver sensitivity. We can, in such tests, change signal power level at predefined levels and see how the receiver will react in terms of tracking, acquisition, and navigation.
5. We can also simulate numerous non-standard situations and signal errors to see how our receiver reacts to them.

These types of test are nearly impossible to do with live satellite signals but are rather conventional with simulators, providing that the simulator supports the correspondent functions. Knowing the *true model* (discussed in Part 2 of this series) and being able to control the signal environment offers many advantages.

The list of possible tests is much longer, and most of them are either impossible or less effective with live satellites.

Two RPSes: The bottom unit functions in playback mode while the top one is operates as a front end for a PC-based software receiver

Record and Playback System: The Recording Function

Record and playback systems (RPSes) have appeared recently as an alternative solution for simulation. They also sometimes referred to as "record and replay systems," a somwhat inaccurate term because such systems don't replay the satellite signal, but rather play back the recorded signal. The played back recorded signal could be quite different from the original satellite signal.

An RPS should not be confused with a simulator, because it lacks one of the three simulator's main features — a controlled environment. That is, unless it plays back a simulated signal, a possibility that we will look at later.

In general an RPS provides a convenient means for repeating a test with live satellites. However, all disadvantages related to live satellite tests are inherited in RPS tests. The two main disadvantages are the absence of control over signal parameters and lack of knowledge of the true model. Only the first test among those we have mentioned earlier could be conducted with an RPS.

RPSes are indispensable when the receiver-medium-transmitter situation is somehow unique. These situations can either be related to the receiver dynamics — for example, in case of flight tests, or to atmospheric conditions, such as ionospheric scintillations — or to transmitter conditions, such as particular behavior of a satellite, pseudolite, or jammer.

A number of flight tests have been conducted with a software receiver, which have provided full access to tracking loops to modify them in accordance with algorithms developed at the Japan

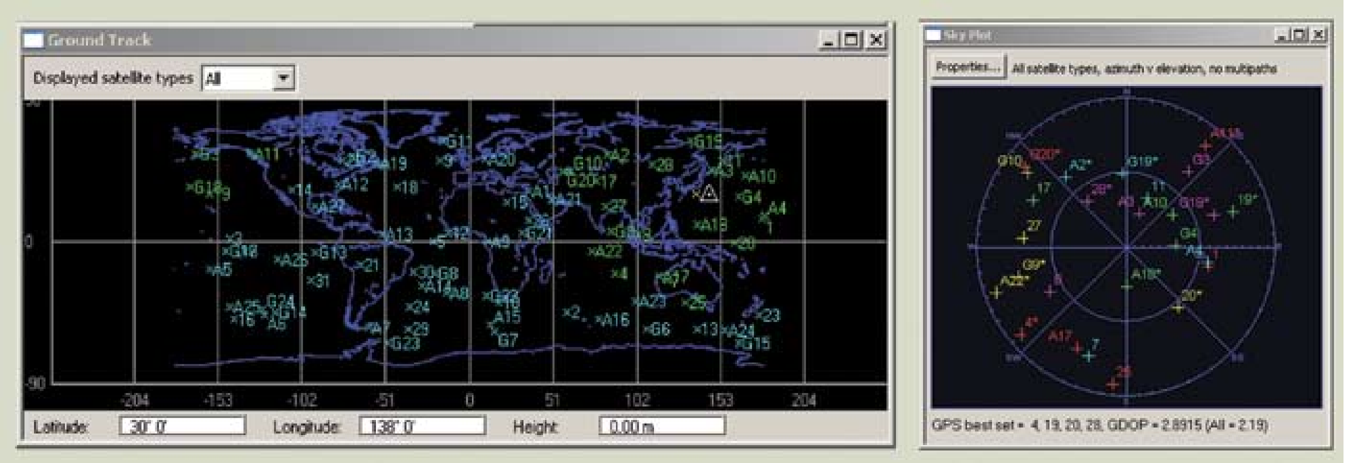

FIGURE 1 Screenshot of RF simulation software showing GPS + GLONASS + Galileo constellations

JAXA aircraft during a flight test (left); on the right, inertial navigation systems used to record flight trajectory and provide aiding data to a software receiver

Aerospace Exploration Agency (JAXA) as described in the article by T. Tsujii et alia (for details, see the Additional Resources section at the end of this article).

The test equipment recorded data from an inertial navigation system (INS) along with the GPS signals. In this case, the RPS was very important because it allowed researchers to work on an airborne navigation system routinely at the desk without any trade-offs, while avoiding unnecessary repetitions of real flight tests.

A similar signal was simulated for the same trajectory. However, some pitfalls appeared. A signal for the flight trajectory has been simulated using our digital intermediate frequency (DIF) signal generator. The signal simulated for the trajectory using 50-hertz INS data was indistinguishable from the recorded signal for the receiver with standard settings.

When the receiver settings were set to a narrow tracking loop bandwidth, a difference between the simulated and recorded signals appeared. We attributed this difference to the fact that the recorded by INS trajectory, used for signal simulation, was less smooth than the real flight pass. Consequently, a different method of trajectory simulation based on real data has been implemented.

This method was based on using tabulated trajectory data from the flight rather than a complete 50-hertz INS recorded data set. The signal generated for the tabulated trajectory was indistinguishable even for narrow-band settings (see **Figure 2**).

The yellow line in Figure 2 shows information from the INS, which is used to aid receiver tracking loops. The third panel shows unaided carrier error, which has a systematic error. This error is compensated using aiding information (see panel 4). For a receiver with the bandwidth set for a narrow band, the aircraft dynamics caused loss of lock for an unaided receiver. With INS aiding, the receiver maintained lock at all times.

This example demonstrates that for new and non-standard tasks, which can be often encountered during research

GNSS RF recorders with OCXO under test with single-channel GPS simulator and development, recording live satellite data as a reference is often necessary. In this case, we used RF recorded data to tune up our simulation technology for an airborne narrow-band receiver.

Recorded data also may prove to be very useful when special events in the signal propagation media occurs. For example, there is an application in which RF recorders are used to collect data to analyze ionospheric scintillation. These data are normally gathered using specialized receivers, which output results of their internal calculations. Therefore, in the latter situation a researcher has neither access to, nor influence upon these calculations.

When using an RF recording, a researcher is working with an actual signal itself and may also have access to more information about an underling process. For example, a researcher may benefit from using the recorded satellite signals with a sampling rate of tens of megahertz instead of processed output of a receiver with a sampling rate of only hundreds of hertz. It also may be advantageous to have the raw data prior to being processed by the tracking loops, because tracking loops behave as shaping filters and may interfere with signal statistical characteristics.

The recorded signal can be also correlated with TEC data delivered simultaneously by a dual-frequency receiver. For such applications, RPSes should have high-quality oven-controlled crystal oscillator (OCXO) clocks to decrease carrier phase noise.

Accompanying photos show an internal view of an RF recorder attached to an OCXO as well as a suite of RF recorders and OCXO undergoing final testing with a GNSS simulator. We conducted this test after the assembly process, and it shows the importance of proper simulation equipment. This RF recorder can also function as a receiver front end. Therefore, we have connected it to a single-channel simulator and a receiver on a computer.

Consequently, this setup enabled us to instantly see whether the signal from the recorder had been successfully acquired, and, if so, would allow us to certify that an assembly has been done properly. Also, by looking at a simulated and measured Doppler we could judge that OCXO is functioning properly. (We had previously conducted tests to ensure the OCXO's performance per specifications before this final test on the receiver itself.)

How Good Is an RF Signal On a Disk?

Before we go further, we should look at this recorded RF signal in detail. How good is it?

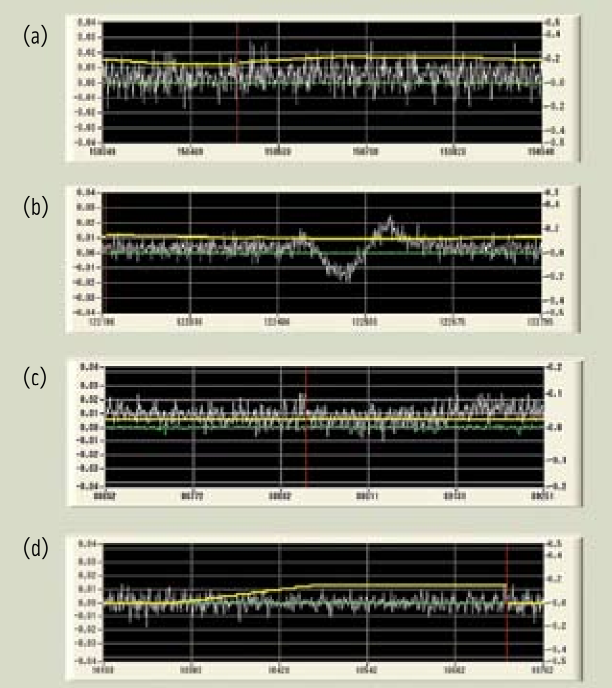

FIGURE 2 Carrier error output from a software receiver set for a narrow band for a) recorded signal, b) simulated signal for trajectory based on 50 Hz INS data, c) simulated signal for tabulated trajectory without aiding d) simulated signal for tabulated trajectory with aiding. Yellow lines indicate the aiding information from an INS. Green line is code error in much larger scale.

Here we have a situation similar to the comparison of analog and digital cameras that we used earlier in discussing simulator types. The digital representation of an RF signal, recorded on storage media can be as good as is required.

We convert analog signals to digital ones because a digital signal is easy to analyze, it is more accessible, and our digital instruments are much more precise than analog tools. For years designers have been using oscilloscopes and spectrum analyzers, which work with digitized signals. In fact, if properly done, this signal conversion imposes no limitations at all.

So, let's look at how an RF signal is transferred to a digitized IF signal. Firstly, the RF signal is down-converted, an operation that keeps all signal features intact and just moves the signal to a lower frequency.

Secondly, the resulting signal from the down-conversion procedure is digitized. However, when the IF signal comes through an analog-to-digital converter (ADC), it changes.

The analog signal on an ADC input is not the same as digitized IF on the ADC output in many respects. Whether this difference is significant or negligible for a system that uses the signal depends on the specific system. In particular, whether a signal played back from an RPS is significantly different from the original one depends on how the RPS ADC and DAC parameters correspond to the ADC parameters of the receiver under test.

Today a lot of specialists from different areas are using simulators, and it is a safe choice for them. Yet, using an RF signal from an RPS creates a slightly different situation. Users may need to better understand digital signal processing in order to avoid some possible pitfalls because ensuring that the parameters of an RPS are in the range required by equipment test specifications is now the user's responsibility.

Of course, digital simulators also employ digital signals and DACs. However, the key difference is in the range of the main parameters. The main parameters of digital IF signal are the signal quantization level (also called bit resolution) and sampling rate (see Figure 3).

Other parameters, such as a bandwidth and IF frequency, are secondary

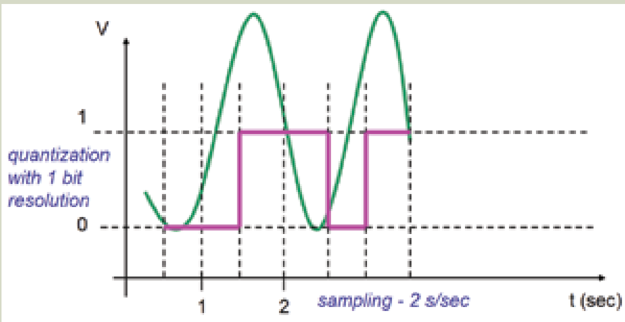

FIGURE 3 Digital signal — quantization and sampling. An analog signal (green) is digitized with one-bit quantization and two samples per second sampling rate to a digital signal (magenta). Note: the sampling for the GPS signal is on the level at least four Ms/sec.

ones. They are largely defined by the sampling. Regarding the difference between an RF simulator and RPS, the quantization level of an RPS could be as low as 1 bit (as on the Figure 3), which comes from the ADC part, while the quantization level of a typical simulator's digital signal (coming from the DAC) is at least 14 bits. That means that the RF signal coming from the one-bit RPS was at some point represented by two values in terms of quantization (Figure 4c). At the same time, a signal coming from a standard simulator was constructed using 16,384 values.

Most commercial receivers have one- to two-bit resolution, and such quantization is quite satisfactory for most of the tests. However, we may not be able to conduct some of the tests we need with this resolution level, such as those related to high sensitivity or interference.

RPS: The Play Back Function

An RPS is capable of playing back a previously recorded signal. This may come, however, at a price.

When we are testing a receiver with an RPS, we are adding an extra front end — actually two extra front ends, the record and the playback elements — in front of the one under test. In that case, the RPS acts as an extra filter between a satellite signal and the receiver being tested (see **Figure 4**).

We shouldn't expect the Signal 1 in Figure 4a to be the same as Signal 2. Even if neither the record nor playback component of RPS applies any explicit filtering, they still represent a filter.

Figure 4b shows an effect from the RPS sampling rate. The sampling rate specifies a Nyquist frequency and correspondingly highest frequency, which is possible to reproduce. For some applications this extra filter plays no role at all.

However, for many tasks recognizing the difference between recorded/replayed, simulated, and live signals is important. The signal received by a receiver is defined by its bandwidth (the yellow polygon in Figure 4b). If the receiver bandwidth is wider than that of the RPS, the received signal will be different

Figure 4c shows an RPS quantization effect on a receiver under test. Not all information in the original signal can be restored with an RPS. A tested receiver may be subjected to different signals in the case of RPS, RF simulator, or live signals. This also depends on the receiver under the test.

Altogether, signal degradation in an RPS is inevitable, but it can be minimized. The quantization and sampling parameters for RPS should exceed those for the receiver under the test. For example, if a receiver has three-bit resolution, than using an RPS recorder with a two-bit resolution is undesirable. A one-bit resolution RPS is undesirable for testing receivers with two-bit resolution and higher. The same is true for sampling rates.

The solution is to use an RPS with high quantization and sampling. High-end RPSes provide up to 50-Ms per second sampling rates and up to 14-16–bit quantization.

These solutions, however, imply very large recorded DIF signal files, easily reaching the level of terabytes. This data load, in turn, makes it necessary to use very specialized real-time computer systems and renders the whole system rather bulky and very expensive. And even such sophisticated systems are not free from shortcomings. They still employ two extra front ends, though these most likely will not affect the signal as far as receiver under the test is concerned.

An alternate solution, which we use, is to completely eliminate the front ends of an RPS playback and a receiver, using the RPS recorder front end instead of the receiver front end. This effectively makes the path of signals 1 and 2 in Figure 4 the same.

An example of an RPS, which we are currently using, is shown in the accompanying photo. This RPS plays back digitized IF signals instead of RF signals; thus, the whole test implements only one RF front end instead of three. Both front ends in the photo work during replay only with DIF signal; so, their RF parts are bypassed.

The recorded data are streaming from the PC through a USB port and from front end through a DIO interface to a basband processor of the receiver under test. The second unit in the photo facilitates the delivery of this streaming data to a PC-based software receiver, which operates in real-time mode.

However, this approach applies only for R&D and design tests, when RF front end testing can be omitted for some tasks. This approach is especially valid when an RPS recorder uses the same front end modules as tested receivers. In the example with tightly coupled INS/GPS receiver described earlier, the recorder used the same front end with a software receiver.

Therefore, the receiver works with exactly the same signal in the case of real live satellite signals and played-back DIF signals. The only difference is related to an extra clock drift, which is another disadvantage inherent to all RPSes when playing back a recorded signal. Each front end is timed by its own clock, usually a temperature-controlled crystal oscillator (TCXO). If this issue is not taken care of, then each front end adds its clock error on top of the clock error from the previous front end.

When the RF signal is recorded, the recorder front end clock drift is added to the recorded signal. Then, when the signal played back, the playback device clock adds its drift to the played back signal, which is already corrupted by recorder clock. That was a reason for OCXO implementation in the RF recorders for the JAXA research related to INS-aided GPS receiver discussed earlier in this article. This issue can actually affect assisted-GPS (A-GPS) tests or other kinds of tests that involve precise Doppler information.

One final disadvantage is that RPSes also lack any ability to adjust or control the signal power.

Altogether RPS with RF playback is not a completely safe choice for overall GNSS receiver testing, although the recording part provides an indispensable tool for many R&D-related tasks. We have described a safe way to play back a DIF signal from an RPS, which allows us to remove two extra front ends from the picture. But even that approach requires a product designer or system developer to ensure that the parameters of the RPS are in the required range.

RPS: The Signal Generation

All the limitations related to live satellites are no longer valid if an RPS plays back a simulated signal. In this case the RPS effectively acquires most of the same functionality as a simulator. In order to simulate such signals, we use a PC-based DIF signal generator, the design and functionality of which we described in Part 2 of this series.

Similar to a simulator, which by definition creates a signal indistinguishable from that transmitted by a live satellite, a DIF signal generator creates a DIF file indistinguishable from that recorded by RPS or RF recorder. The generated DIF signal can be played back in the same way as a satellite signal recorded from live satellites.

With such an approach a user still is not being able to control any parameters in real time in the course of a simulation. By contrast, with a conventional simulator we can adjust power for specific satellites or channels in real-time and watch how our receiver reacts to those changes.

The advantage of generating a signal for an RPS is the possibility to create a signal with any required quantization and sampling. In this case, a quality of the signal will be defined by the specification of a playback front end, and in particular by the DAC. In general it provides much higher specification than for a recorded signal.

However, the process of signal generation on a PC is very slow. It is a function of quantization and sampling, and the number of channels including those for multipath generation. Relying on PC-generated signals is quite acceptable for some R&D tasks, but may prove rather difficult to accommodate more conventional testing, especially where numerous tests are required. A range of tests that normally takes a day with a simulator, may take a week or two with preparing and playing back generated files.

As an example of R&D tasks for which such an approach is not only acceptable but very advantageous, we look here at the signal generated by a

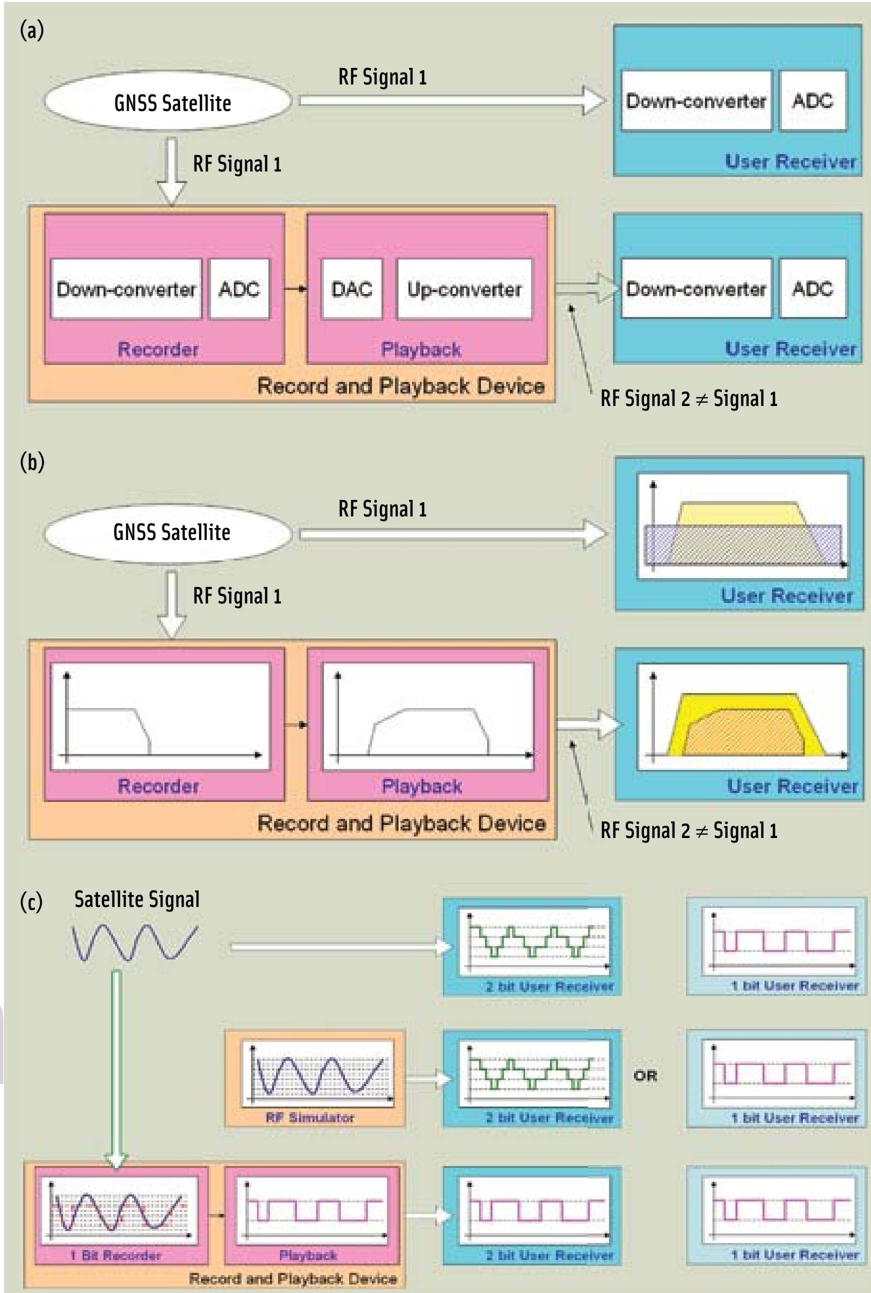

FIGURE 4 a) Testing with an RPS versus live satellites, b) testing with RPS: how RPS sampling rate affects tests, c) testing with RPS: how RPS resolution affects tests

DIF signal generator and compare it with one that has been recorded during the flight of an aircraft (see **Figure 5**). The signal is indistinguishable from the real one, but it was simulated with the presence of ionospheric scintillation and enables researchers to work on countermeasures in the receiver using INS aiding (discussed further in the article by T. Tsujii et alia).

Two different recorders were used during the flight test. One recorder was equipped with an OCXO and another with a TCXO. Figure 5 shows the TCXO clock drift in comparison with its absence for a simulated signal.

Figure 6 shows the total simulation suit. A trajectory generator has output a true trajectory, based on data recorded by the INS during the flight. The DIF generator has generated the GPS signal for this trajectory. The simulated signal also included ionospheric scintillation. Aiding data from real INS, recorded during the flight, and INS Simulator have been used to aid the software receiver tracking loops.

One can definitely use such simulation solution for the tests we mentioned in the first section, which were impossible to do with live satellites and an RPS playing back the recorded live satellites signal. A user, however, must check if the DIF signal generator can support such tests and whether the RPS playback front-end parameters fit their test specifications.

Currently in our tests the generated signal is processed by s software receiver in post-processing mode, where the receiver works with the signal stored on media. The receiver also works with the signal streamed to the front end in real time through an RPS.

The signal is not converted to RF and a DIF signal is streamed through the front end. For the next series of tests, that we are planning, a number of off-the-shelf receivers will be used to process the simulated signal.

We would like to see how various off-the-shelf receivers behave under scintillation conditions. For that purpose the simulated signal will be converted to RF. Because we have access to the inside (source code and design) of the complete RPS chain, we can ensure that the signal is generated with parameters that satisfy each receiver under the test.

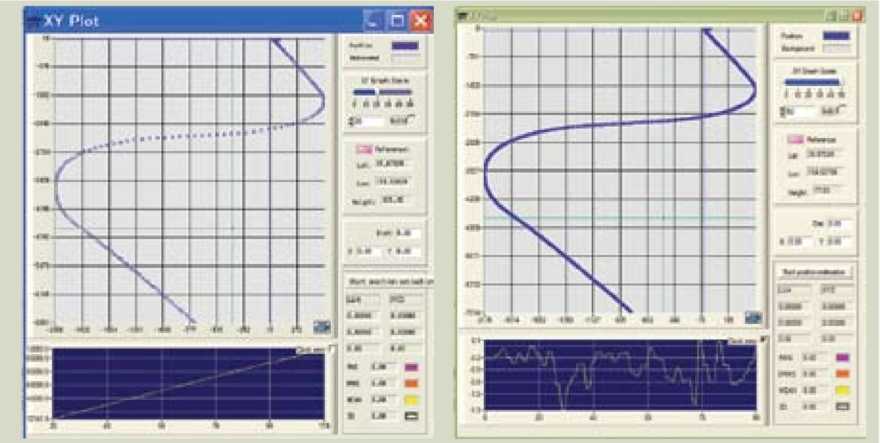

FIGURE 5 An iPRx receiver screenshot shows the results of navigation with recorded (on the left) and simulated (on the right) GPS signals (courtesy of JAXA). Notice the difference in the clock error in the bottom graph of both panels. A clock error on the left panel is coming from a front end with a TCXO.

RPS: Mixing Simulated and Real Signals

An interesting feature brought by a RPS

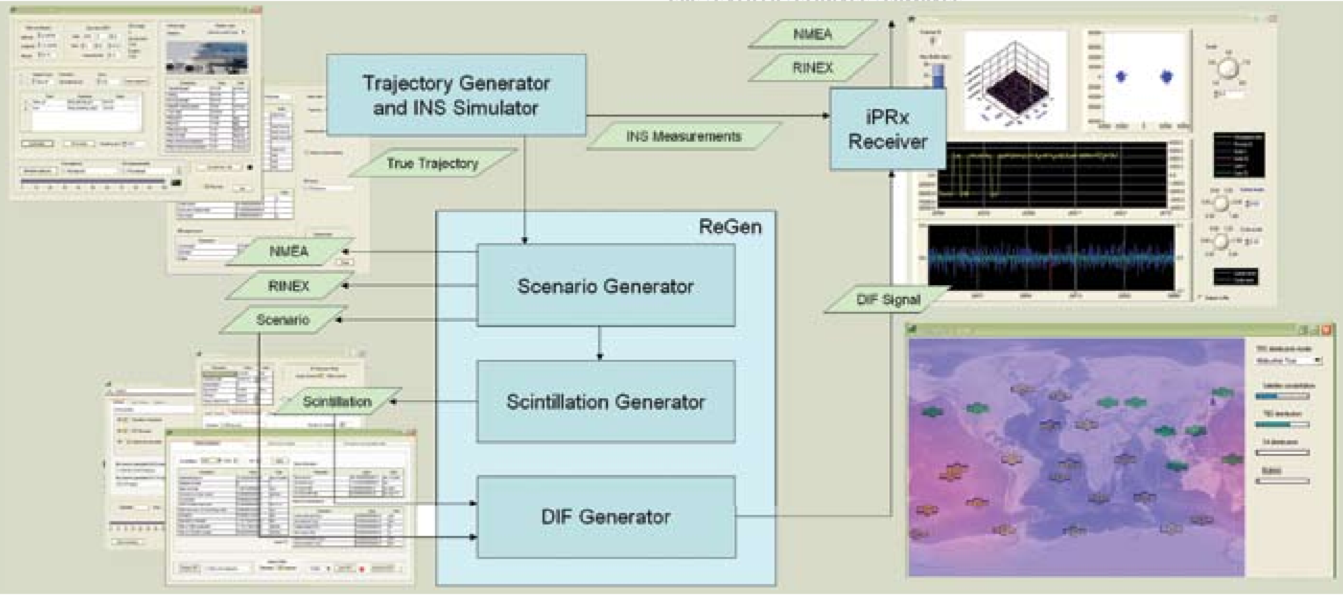

FIGURE 6 Simulation suite for tightly coupled INS/GPS receiver. A DIF generator provides extended control over ionospheric modeling and visualization (on the right).

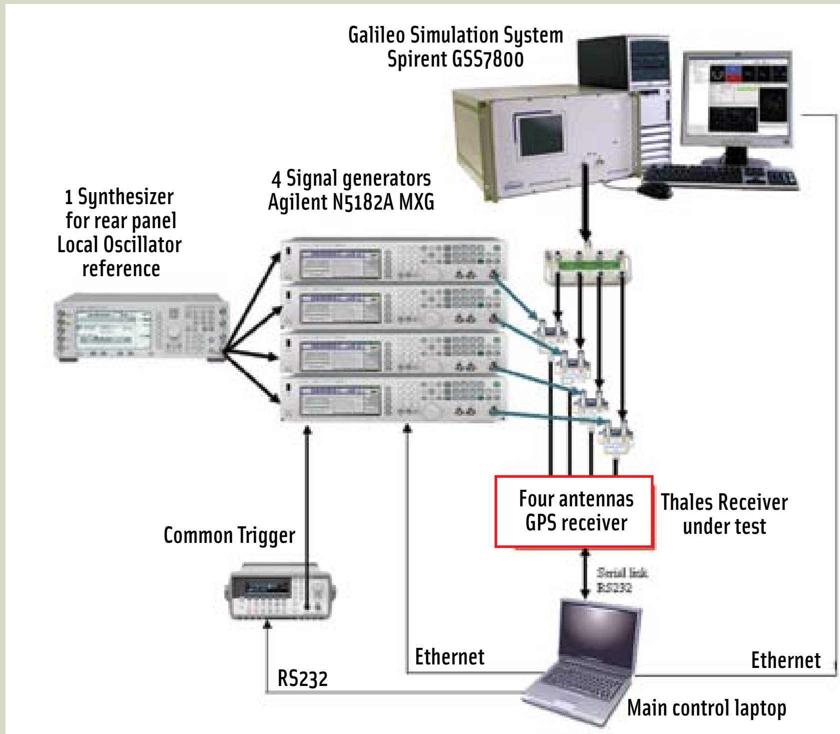

FIGURE 7 Jamming environment test setup

FIGURE 8 Jamming environment simulation visualization in Google Earth (courtesy of Thales Avionics)

system is the possibility of combining a simulated signal with a live satellite signal. This feature can be used in two main application areas — for research into interference and for designing new GNSS systems.

Artificially generated noise or signals can be combined with recorded live satellite signal to simulate interference conditions. This approach has advantages in comparison to that where both signals are simulated. However, as we described in the previous section, high values for the quantization parameter of the artificial signals would be required.

A less demanding RPS application is found in conducting a feasibility study or preliminary research into design of a new GNSS. In that application, simulated signals for new satellites or signal designs can be added to real live signals in order to analyze how all of these signals operating simultaneously would affect a receiver.

In order to do this properly, we have to synchronize the two signals. If the mixed signals are related to different satellite systems, such as, for example, GPS and GLONASS, then the synchronization can be done with accuracy within a difference between system time scales. Although most multi-GNSS receivers allow for a time shift between the systems, some level of synchronization is required.

If we want to simulate the signals of a satellite from one or more GNSSes in combination with signals recorded from live satellites, then the synchronization should be much more precise. This in turn will require us to have an embedded receiver in the mixing device to time mark the corresponding recorded and simulated signals. Our software receiver, for example, can accurately mark the beginning of a GPS frame within samples of the digitized satellite signal.

Jamming Environment Simulation

Thales Avionics has constructed an advanced test to simulate a jamming environment. The equipment configuration of this test is shown in **Figure 7**. This is another example of mixing signals for research purposes. In this case, all the mixed signals — involving GPS and Galileo signals — are simulated.

The test was built around a GPS/Galileo RF simulator to research the performance of a multi-antenna, anti-jamming aviation receiver. The system allows operators to control the simulated distance to a jamming source by adjusting signal power in real time. It also enables control the direction of arrival of a jamming signal by adjusting the phase of each reference clock in the signal generators.

Every kind of jammer modulation can be downloaded into the synthesizers and synchronized to the scenario played by the GNSS simulator.

Real time mission visualization has been provided through a Google Earth interface. (**Figure 8** shows vehicle movement in real time during the test, the jammer, and the protection area around the vehicle carrying the antijam receiver.

Simulator Specification Parameters

Here we consider specification parameters mostly for RF simulators. Only

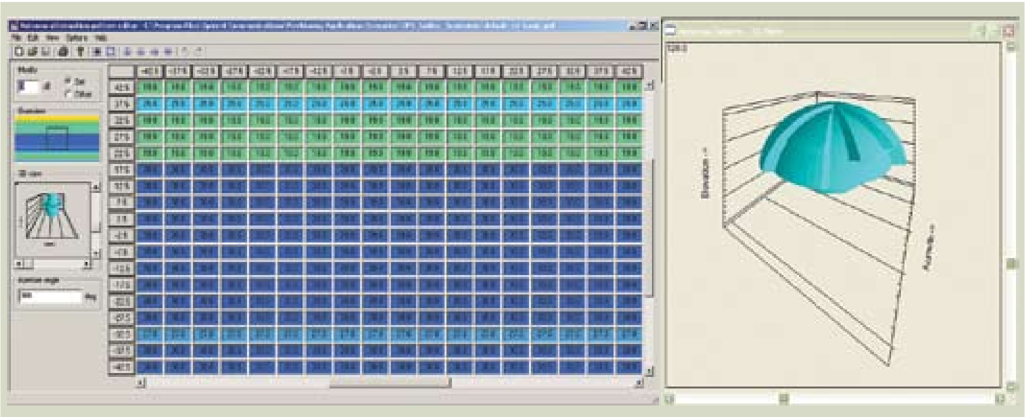

FIGURE 9 Antenna pattern editors for transmitting and receiving antennas in simulator software suit.

some of the parameters of a signal generated from an RPS can be guaranteed because the recorded signal came from a real satellite — which generally is out of reach of user control.

Some parameters also may be less relevant for an RPS because the features of RPSes that we described earlier may mask most of these parameters. So, in the case of RPSes, we will consider only a small part of these parameters.

The first group of parameters describes the quality of code and carrier phase generation. They are reflected in pseudorange accuracy, uncertainty in code phase offset, and uncalibrated error in range generation. This last error includes uncertainty in distance, ionospheric and tropospheric delay, and satellite clock error.

For a high quality simulator pseudorange accuracy should be within ± 0.3 meter RMS, including inter-channel bias. The uncertainty in the pseudorange rate with respect to the simulator reference oscillator should be on the level ± 0.03 meter/second RMS.

Inter-channel code and carrier alignment represents the difference in code and carrier phase at the RF output between any two channels simulating the same satellite. This parameter is around zero for digital simulators and may have some value for analog simulators (see Part 2 of this series), especially for carrier alignment. All these parameters must be one order of magnitude better than the expected performance the receiver under test.

The other group of parameters relates to generated power levels, most of which are not applicable to RPSes at all. Uncertainty in overall simulated power level under all conditions should be within ±1.0 decibel or, at the most, ±2.0 decibels. A simulator should allow users to change signal power with at least one-decibel steps for each channel independently.

The next group of parameters is related to the quality of a simulated satellite's carrier signal. They are described by phase noise and carrier-frequency stability. Carrier frequency should be centered with an accuracy of not worse than a few hundred hertz even after a few years of operation.

The quality of the carrier is closely related to the quality of simulator master clock or clocks of both RPS front ends. We recommend that the master clock stability over one day (after allowing for a sufficient warm up period) should be within $\pm 5 \times 10^{-10}$. The same requirements are applicable for an RPS. Our RPS recorders for scintillation monitoring and INS/GPS tight coupling use OCXOs with such a specification.

A simulator should also support all the parameters for various vehicle dynamics. This is not very important for many applications, but it can give a hint about the capability of a simulator. Analog simulators are limited to lower user dynamics whereas digital simulators are basically limited only by the capability of their RF front-end filters.

Simulators intended for production tests should also provide good automation support. For instance, it may include an ability to output a 10-megahertz reference frequency in order to enable synchronization of an aviation breadboard with a simulator and to avoid clock drift effects. Another standard feature is to have one pulse-per-second (1PPS) modes and a trigger start for coordinating a simultaneous start with other equipment or other simulators.

Does Size Really Matter?

Essentially the physical dimensions of simulation equipment are always in the specification. For lab tests the dimensions are more flexible as the unit merely needs to fit into a standard lab rack mount. In case of RPSes, field recorders need to be smaller rather than bulky.

Nonetheless, all this equipment is not intended for a consumer market and, unless it is a manufactured in quantities, a small size may signify a compromise of quality. If we look, for example, at computers, desktop solutions still provide better performance specifications than laptops and far better one than handheld computers or smartphones.

What *really* matters in simulation equipment today is the graphical user interface (GUI). A user-friendly, intuitive GUI is not a luxury any more; it is a requirement. We no longer can say that simulator users must be specialists and able to guide themselves through a complicated set of user actions or expect to struggle along without a user-friendly GUI.

This doesn't mean that a user of simulation technology is not a specialist. The user is definitely a specialist, but users do not need to spend more of their time on tasks than is necessary. A GUI should help users to grasp necessary information quickly and provide better interaction between them and the device with which they are working. At the end of the day, a user-friendly GUI is a way to save valuable time. It is also more fun and as such brings more satisfaction from the job.

Normally minimum GUI requirements include such visual information as:

- sky chart
- channel power levels
- vehicle instrument panel, which is

especially informative for aircraft-related tests
- detailed channel information
- true position information
- satellite ground track.

Useful extra features for more advanced interfaces may include visualization of ionospheric errors, such as TEC and S4 distribution, overlapping each other and the satellite constellation (see Figure 6). The GUI's basic functionality also should provide a user with the ability to control power for each satellite in real-time.

Today a basic RF simulator should graphically support many functions that were previously provided only by high-end simulators. One definitely would expect from a simulator a multipath editor (as discussed in Part 2), and antenna pattern editors for at least the receiving antenna (see **Figure 9**)

Conclusion and Guidelines

In looking at options for test solutions, a digital RF simulator is still the optimal one in most areas. When choosing one, make sure that all desired tests are supported and all important models and parameters are editable and configurable. Don't underestimate the importance of the GUI, because it will give you better control over the tests and save you time.

RPSes and RF recorders give a possibility to record valuable and unique signal data and in that respect represent useful and powerful tools for R&D.

When playing back RF signals from an RPS, make sure that its parameters satisfy your test requirements. Be aware that the RF signal played back from an RPS is changed in respect to the original satellite signal and is, in general, inferior to a signal produced by a simulator. Make sure that the RPS allows you to conduct all required tests, because most of the standard tests cannot be supported by recording and playing back live satellite signals.

For a solution in which a signal for playback is generated in the software, look more carefully at the DIF generator in charge. As with an RF simulator, make sure that all important models and parameters are in place, editable, and configurable.

For many R&D tasks, where the RF part can be bypassed, an RPS with DIF playback may present a very useful simulation solution. In this case, a recorded DIF signal can be streamed to a baseband processor of the receiver under test bypassing two extra RF front ends.

Additional Resources

Tsujii, T., and T. Fujiwara, Y. Suganuma, H. Tomita, and I. Petrovski, "Development of INS-Aided GPS Tracking Loop and Flight Test Evaluation," 2009 International Symposium on GPS/GNSS, Jeju, Korea, November 4–6, 2009.

Manufacturers

The tests described in this article used the multi-channel multi-GNSS GSS6700 and GSS7800 simulators, single-channel GSS6300 simulator, and SimGen software suite from **Spirent Communications**, Paignton, United Kingdom. Real-time software GNSS iPRx receiver, GNSS RF recorder with OCXO, a Replicator RPS, and ReGen GNSS DIF generator from **iP-Solutions**, Japan. Four N5182A MXG signal generators from **Agilent Technologies, Inc.**, Palo Alto, California, USA, were used in the anti-jamming tests as well as a pre-production four-antenna digital GPS receiver from **Thales Avionics**, Valence, France. The integrated INS/GPS unit used in the flight tests was the Micro-GAIA developed by the **Japan Aerospace Exploration Agency**, Tokyo, Japan, tightly coupled with an iPRx receiver from iP-Solutions.

Authors

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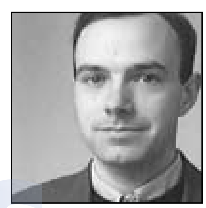

Jean-Michel Perre received his engineer diploma in radio communications at the Ecole Superieure d'Electricite (SUPELEC), Paris. He joined Thales in 1994 to work on antenna signal processing and develop direction-finder and jamming-mitigation prototypes. Since 1998, he has been working on GNSS solutions from mock-up to industrial products for Thales Avionics in Valence, France.

Bryan Townsend has more than 20 years experience in various GNSS fields including receiver design, ground- and space-based augmentation systems, and real-time kinematic positioning as well as terrestrial-based systems. He has authored and co-authored more then 50 papers on these subjects.

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