White Paper

Integrating GPS into Consumer Products

An R&D engineer's guide to integrating and testing global navigation satellite receivers

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Introduction: Consumers' Growing Reliance on Positioning Technologies

Once, consumers' only day-to-day experience of satellite positioning technology was in their vehicle's satellite navigation system—or, possibly, sophisticated hiking equipment.

But more recently, that landscape has changed. Smartphones, tablets and other personal devices are increasingly location- aware, and members of the public have come to expect everyday technology to show them their position as a blue dot on a map—instantly, accurately, and everywhere—whether under tree cover, in towns, or even indoors.

As a result, engineers tasked with integrating positioning technologies into consumer products are now commonly required to define and implement new regimes to ensure that the chosen GPS, GNSS and hybrid positioning systems function to ever- tighter specifications.

This can be challenging. Test equipment manufacturers publish specification data, often with little interpretation to give meaning to the numbers. But for device manufacturers, the development consequences of choosing the wrong test equipment—and running ineffective or inconsistent tests—can be severe.

We hope this white paper will give engineers some clarity on the issue, summarising the key areas and outlining some common pitfalls surrounding testing procedures and apparatus.

Among other topics, it covers:

- Recent and future changes in the satellite signal environment
- Supplementing GPS and GNSS with other kinds of positioning technology
- Nine key positioning performance characteristics
- The consequences of poor performance
- Choosing the right testing equipment for your application
- What to look for—and pitfalls to avoid.

However, if you would rather talk directly with an engineer, please feel free to contact us using the details below. Our team of positioning specialists would be delighted to discuss your particular application or query.

Global Satellite Positioning: An Overview

Increasingly, consumer devices are expected to be aware of their location. Cameras should know not just when a picture was taken, but where. Exercise equipment can tell us how many calories we've burned, based upon how far we've been. New vehicles automatically inform the authorities of the location of a crash, and watches adapt to the local time zone before we've even thought to check.

Frequently, this sense of position, movement and universal time is calculated—at least in part—by reference to satellite RF signals.

GPS is by far the best known of these systems—to the extent that it is often wrongly used as a generic term for satellite positioning. But in fact GPS is only one of a growing number of satellite constellations available to location-aware devices:

- Russia's **GLONASS** system is fully operational, has global coverage, and is itself almost two decades old.
- **Beidou / Compass** is China's growing satellite constellation. BeiDou-2, the second-phase constellation covering the Asia- Pacific region, is active now, with fifteen satellites broadcasting on three frequencies. Global coverage is expected by 2020.
- Likewise, the European Union's forthcoming **Galileo** system will broadcast civil signals, and is developing apace.
- These global networks are supplemented by an array of further, regionally-focused augmentation systems, like Japan's **QZSS**.

By the end of the decade, there will be around four times as many positioning satellites available. Devices that can make use of these will benefit from dramatically enhanced coverage and reliability in their calculations.

Accordingly, instead of GPS, it is more accurate to refer to multi-GNSS: multiple Global Navigational Satellite Systems.

Advancing technology and falling prices are making multi-GNSS capability increasingly accessible in consumer devices, and as soon as 2020 it is likely that users will judge the dependability of their positioning systems by higher, multi-GNSS standards.

Integrating Multiple Positioning Techniques

Calculating location from satellite signals is, of course, only one way to give a device a sense of its relative position in time and space. Inertial sensors, Wi-Fi signals, cellular networks and even miniaturised barometers can also play a role.

The ability to refer to fixed, authoritative and independent sources of time and position information gives GNSS technology obvious advantages—particularly where a device is not aware of its starting position, or in reducing the effect of cumulative errors.

In reality, though, it is rare for any positioning method to be used in isolation. Combining multiple technologies can improve resilience, accuracy, and coverage where a satellite, cellular or Wi-Fi signal is weak. Accordingly, part of the integration engineer's challenge is to define and test the way a device prioritises and resolves the various readings—particularly where they give conflicting results.

The Importance of Thorough Testing

The more location-aware devices become an accepted part of everyday life, the lower consumers' tolerance for poor accuracy, coverage or performance. As people come to rely on positioning technology, manufacturers' reputations hinge not merely

on devices being able to provide a location, but on providing it accurately, consistently and continuously, in a wide range of conditions.

The consequences of unreliable GNSS performance in the field are potentially catastrophic. Where once the most serious consumer outcome might have been taking a wrong turn down a dirt track, devices are increasingly used in contexts where safety and significant finances are at stake.

This doesn't merely apply to location calculations. Where satellite signals are used as an independent source of time, slight inaccuracies in—for example—time-stamping transactions where prices are changing fast could cause major confusion and damaging losses.

The implications are no less serious for device manufacturers themselves. Beyond the reputational and commercial damage of selling—and possibly recalling—unreliable equipment, discovering that a system does not perform as it should can lead to delays and waste at every stage of the product cycle.

This makes it essential to test systems thoroughly, exhausting all eventualities, both in terms of usage and signal environment… and to ensure your test setup is well suited to the job.

Nine Key Positioning Performance Characteristics

The suitability of each device for its purpose will depend on the exact operation and likely operation conditions. Naturally, therefore, each testing regime will be subtly different.

However, there are nine key characteristics that commonly combine to influence the user's experience of their positioning device:

1. **Cold Start Time to First Fix**
   This is a particularly important test, because it is the first thing a user notices. In short, it is how quickly the device can acquire a satellite lock from scratch—with no current almanac or ephemeris data, and no memory of its time or position. It is best performed a number of times, at locations that are thousands of kilometres apart.

2. **Warm Start Time to First Fix**
   This tests how quickly the receiver can pick up a signal it has been used fairly recently. The almanac and time are already stored in its memory, and its location is within 100km of when it was last used, but the ephemeris data is either unknown or out of date.

3. **Hot Start Time to First Fix**
   This reflects the majority of the user's experience, if they use the device on a regular basis. The location is close to where the receiver was last used, and the memory has full time, almanac and ephemeris data; all that is required is a signal.

4. **Acquisition Sensitivity**
   Defines the minimum received signal power at which a receiver can obtain a satellite fix. This is important to prevent user frustration.

5. **Tracking Sensitivity**
   This test—which measures the signal power a receiver needs to maintain satellite lock—is important because it will highlight if there are errors in the receiver's tracking loop design.

6. **Reacquisition Time**
   When satellite signal is lost—for example by going into a tunnel, under a bridge or indoors—this test measures how quickly the receiver can find it again.

7. **Static Navigation Accuracy**
   Quite simply, how close the receiver's reported position is to its real location, when still. This test is best performed under controlled conditions, to allow for external variables influencing the result.

8. **Dynamic Navigation Accuracy**
   Taking a series of measurements while the device is moving along one, two or three axes. Such tests can also include changes in speed and direction.

9. **Radio Frequency Interference**
   Because GNSS signals are low powered, receivers are particularly vulnerable to interference—whether by deliberate jamming or, more usually, accidental noise. This test measures a device's susceptibility to problems from any given radio frequency.

When to Test Positioning Performance

To avoid unwelcome surprises delaying a new product's introduction, or complaints and warranty issues from users in the field, integration engineers must test positioning performance at every stage, from receiver selection to production and beyond.

Obviously, the earlier an issue can be identified, the better:

Testing during the receiver selection phase will help to eliminate receivers that don't meet the performance standards required of the finished device.

Testing during the integration phase will help to confirm the suitability of chosen receiver components, and to determine their optimum placement within the wider device.

Product verification testing checks that the positioning technologies conform to relevant standards, whether set independently or, in the case of a supply chain, by a manufacturer.

Production line checks are important to ensure the positioning capabilities of each device function as expected before shipping. Errors here can lead to complaints, recalls, warranty issues or—conversely—perfectly good product needlessly going to waste.

Field service/aftercare tests will help to pinpoint and isolate problems issuing from the positioning technologies within the device (either problems within the technologies themselves, or problems caused by an external factor preventing them from working properly).

Common GNSS Test Approaches

There are three main ways to supply the satellite signals required to confirm a device is dealing with them as it should. Each has advantages, and it may be that a combination of approaches is appropriate to cover the various stages of tests.

"Live Sky" Testing

The cheapest and simplest way to confirm that a device's positioning capabilities work is to see how it handles actual signals from satellites in real time.

There are, however, numerous drawbacks to this approach. As satellites are constantly in motion, standardised tests cannot be re-run, giving no scope for genuine like-for-like comparison testing under controlled conditions.

Similarly, there is no way to test performance under different signal and usage conditions, and under regional satellite networks, without physically taking the system there and performing the relevant test runs.

For example, the only way to Live Sky test how a system handles multipath errors with QZSS signals at 70mph, is to fly a prototype to Japan and drive it at speed through a built-up area.

As consumers come to rely on the accuracy and consistency of the position generated by their location-aware devices, live sky testing on its own is simply not rigorous enough to guarantee the kind of performance consumers expect.

Record and Playback

To give repeatable test runs from a variety of realistic signal environments and tests, Record and Playback systems enable the engineer to perform a test once, capture the resulting signal inputs, and replay them with absolute fidelity.

What's more, a library of common tests from around the world is available, enabling engineers to test a device using real signals, locations, movements, interference and atmospheric effects, repeatedly, from the comfort of the lab.

However, such methods can only use test runs and signals that already exist. They cannot predict performance with the next generation of Galileo and Beidou satellites, or use unusual scenarios to evaluate a system's capabilities when pushed to its limits.

Multi-GNSS Simulation

Simulation gives engineers the power to see how a device responds in virtually any signal environment they can imagine. Satellite positions, interference, movement, rotation, location anywhere on Earth (and space), even attempted hacking and security threats—all are within reach with the right simulator.

Simulation also neatly addresses the issue of multi-GNSS performance in future signal environments. Devices being designed to still be in use from 2020 may need to be tested for their ability to handle signals from satellites that have not even been launched yet. Many GNSS simulators are already equipped to create such signals, based upon specifications released by China and the EU.

Although simulation is usually the most expensive approach in terms of equipment, it is by far the most flexible and comprehensive—and saves budget on iterative test runs in far-flung locations. It is therefore widely used in contexts where reputation, customer satisfaction and safety are important.

There is, however, one key issue. Because the signals are simulated, the quality of the simulator makes an enormous difference to the reliability of the test.

Specifying the Right Multi-GNSS Simulator

There is significant variety in the quality, accuracy and reliability of signals produced by GNSS simulation systems. And, confusingly for many development and integration engineers, the lengthy specification lists supplied by manufacturers apply more to features and capability than to accuracy and performance—so the breadth of the frequency dial and number of channels, rather than any measure of the quality of results.

This presents a significant challenge—and an important one, because a functional device experiencing difficulties due to poor test signal simulation could lead to:

- Poor choices in the selection and integration of receivers, chipsets, antennas and protocols;
- Long delays in new product introduction, redesigning devices for no reason;
- Damaging quality control issues between manufacturers and tier one suppliers;
- Functional devices being wasted after needlessly failing production line tests.

For any test to be meaningful, there needs to be no possibility of confusing errors in the device with inaccuracies introduced as part of the the test itself.

Accordingly, all test apparatus must always be more accurate—by an order of magnitude—than the device under test.

This means if a device is expected to be accurate to within 10m, the test equipment should be reliable to within 1m. If the device's acceptable margin of error is centimetres, then the test resolution should be millimetres.

Unfortunately, simulator accuracy is hard to quantify in a bite-sized, specification-sheet format. So we ran a number of illustrative tests.

Consistency at Low Power

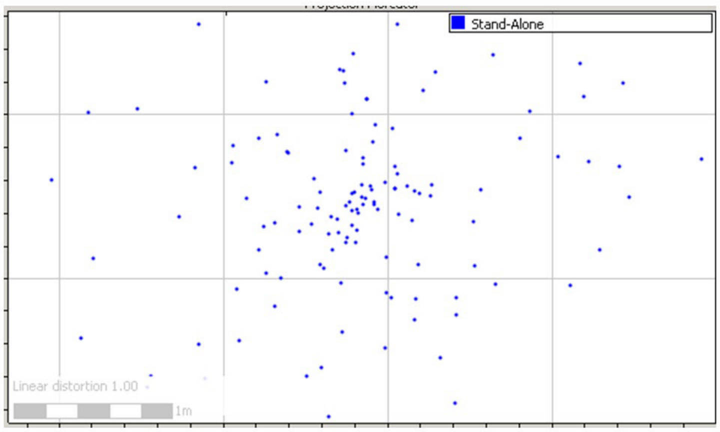
GNSS positioning signals are transmitted at low power, where the ratio of noise to signal makes them difficult to identify. This is exacerbated by many consumer product applications, where a device might be expected to work well surrounded by buildings or tree cover, in a vehicle or indoors, or in an environment with significant RF interference.

Scenario	Received RF Power Level (dBm)—Typical Values
Open sky, no multi-path—ideal signal environment	-125 to -130
Light urban, with multi-path—weak signal environment	-125 to -145
Dense urban, with multi-path—weak signal environment	-125 to -155
Indoors—very weak signal environment	-150 to -165

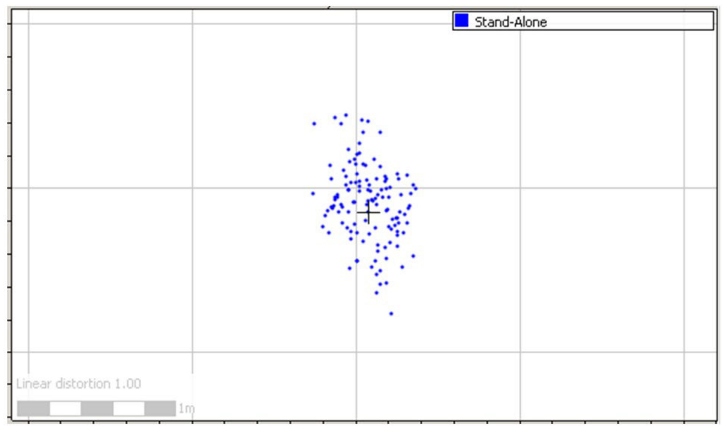
A good GNSS simulator for consumer device use should therefore be able to give consistent signal accuracy, even at the low extremes of its operating spectrum. For example, some multi-use RF signal generators, not designed specifically for satellite positioning use, struggle to maintain accuracy as the power level is dialled down.

To demonstrate, we performed parallel tests on the same, industry standard satellite receiver at a signal level equivalent to that a consumer device might receive a few feet indoors. Everything was identical, except the simulator: one a Spirent GSS6700, the other an unnamed alternative. The test was repeated 100 times, and the positioning results plotted on a graph:

Alternative



Spirent



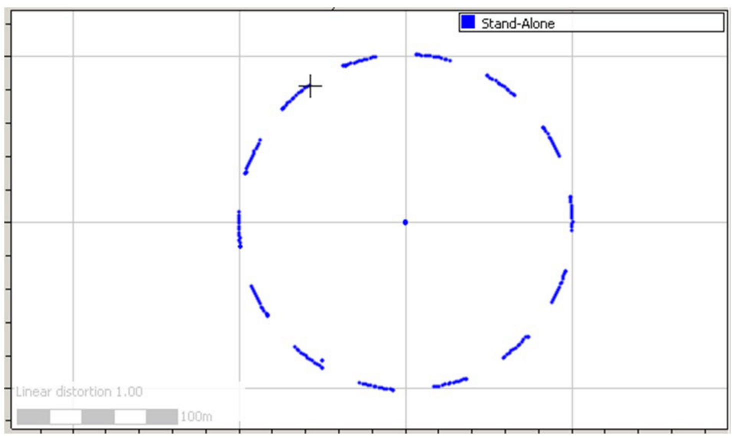
Due to a phase noise issue, the low quality simulator introduced inaccuracies of several metres.

If such a standard test were performed with the poor quality simulator in development lab conditions, an integration engineer might easily assume this poor performance was due to the receiver, potentially jeopardising a supplier relationship, or delaying a new product's introduction for no reason.

Dynamic Signal Stability

We repeated the procedure, with a simple test that might commonly be used to prove a device's dynamic navigation accuracy, coping with both velocity and dynamics.

This time, we set the simulation as a moving consistent circle, 200m in diameter, at a speed of 45 m/s. To make matters easier, we increased the signal power slightly.



With the Spirent simulator, the receiver produced an accurate circle. But with the alternate test set simulating the signals, the receiver failed to achieve satellite lock at all. Again, under development conditions, this second result could be interpreted as a serious fault in the device under test, when in fact the issue is with the simulator itself.

Conclusion: First Test the Test

The conclusion for any engineer is clear: simulation is by far the most reliable way to measure the positioning parameters that will matter to a consumer in the field—both now and in the future. But the accuracy and consistency of the simulated signal can make a huge difference.

Before you test your device, you must first test the test apparatus itself.

This process is essential for establishing a known, confident benchmark, and is less daunting than it might first appear. Any reputable GNSS simulation manufacturer will usually agree to practical demonstrations and a side-by-side trial, and give you personalised advice on which kind of test regime and equipment is best suited to your unique application.

Finally, if you are in any doubt at all, please do not hesitate to ask an expert. Your investment in GNSS testing is significant, and the potential damage from making a poor choice over testing could be even more so.

Our engineers deal with this technology every day, and are more than happy to ensure you have the right test framework in place to work with confidence at every stage of your development, integration and production.

About Spirent Communications

Spirent Communications (LSE: SPT) is a global leader with deep expertise and decades of experience in testing, assurance, analytics and security, serving developers, service providers, and enterprise networks.

We help bring clarity to increasingly complex technological and business challenges.

Spirent's customers have made a promise to their customers to deliver superior performance. Spirent assures that those promises are fulfilled.

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