Testing Military Navigation Equipment

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TESTING MILITARY NAVIGATION EQUIPMENT.

Accuracy, integrity and availability are all major challenges for satellite-based navigation systems, particularly in safety critical environments. There are many techniques and technologies currently existing, and under development, to improve the current performance.

Testing is a critical element to achieve this desired improved performance. The primary aim of this paper will be to present some techniques and benefits for testing military navigation and positioning systems under controlled laboratory conditions using simulation techniques. The focus will be on testing Integrated GPS/Inertial sensors. Techniques for simulating Inertial-only, GPS-only or blended GPS/Inertial position solutions will be covered. This paper will detail how the user equipment under test behaves as if it were receiving RF signals from real satellites when installed on a vehicle performing complex and/or high-speed manoeuvres. This paper will also present the key elements of the test requirements, focusing on the current interfaces. A summary of the simulation and test equipment involved.

In addition to GPS/Inertial navigation, this paper will also cover the challenges and various techniques available for testing satellite navigation sensors in the presence of environmental interference and/or intentional jamming. Various approaches will be presented and the advantages and issues to consider with each approach will be discussed.

1.0 INTRODUCTION

The recent advances in military navigation technology have correspondingly driven a need for more testing to confirm the performance of particular enhancements and also in relation to the qualification/validation of the navigation equipment.

Since the early days of GPS, there have essentially been two major alternatives available to those wishing to test a navigation system, field test and laboratory simulation. Today, best practice indicates that most testing is done under controlled, repeatable conditions in the laboratory. This enables both nominal and adversarial conditions testing, including testing to the limits of both real and theoretical performance. Field testing has its place as an often essential reality check, enabling lab results to be confirmed in the real-world environment or theatre of operations.

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2.0 GLOBAL POSITIONING SYSTEM (GPS)

The GPS satellite navigation system was originally designed and funded as a military navigation system. The removal of selective availability in 2000 improved the accuracy for non-military applications using the L1 Coarse Acquisition (C/A) code to better than 10m in many operational scenarios. This improved accuracy has enabled the explosion of commercial GPS applications that we are seeing today.

In the military sphere, the L1 and L2 P(Y) code encrypted signals remain the NATO standard for military Precise Positioning System (PPS) receivers. Much of the currently available and fielded receiver technology uses these signals. Significant efforts have been focused on improving the integrity, availability and accuracy of these receivers, including in the presence of intentional interference or jamming signals. For aircraft and missiles it is common to couple GPS with inertial sensors as one way of countering both the core deficiencies of the GPS system and the potential threats such as jamming. GPS and inertial navigation systems are strongly complimentary of each other and, used together, represent a high accuracy solution that can be relied upon in many conditions.

The United States continues to invest in the GPS system. This investment includes the specification, design and launch of new satellites including the new Military Code or M-code signal. The initial M-code satellites have already been launched, with additional launches planned over the next decade as the current satellites reach end of life.

3.0 OTHER GNSS SYSTEMS

While US sponsored GPS is the only GNSS with a fully deployed constellation of operational satellites, there is a considerable effort in bringing other GNSS to a global marketplace. These are presented here only briefly for completeness but otherwise are outside the scope of this paper.

Development of the Russian GLONASS system began in 1976 and was completed in 1995. Recently Russia has, with India as a program partner, committed to restoring the system to full operational capability (FOC) by 2011.

The European Union has committed to the design and validation of the Galileo system. A prime difference between this and the other systems is the proposed civil focus of the Galileo programme. Galileo is designed to be inter-operable with GPS raising the possibility of combined GPS/Galileo receivers in future, bringing benefits for users of additional satellite availability and improved integrity. Spirent is an official supplier of RF Constellation Simulators (RFCS) to the Galileo programme. The RFCS are being used for testing the ground monitoring stations and prototype user receivers.

China has indicated it intends to expand the current geostationary Beidou navigation system into a full medium-earth-orbit GNSS constellation, according to China news agency Xinhua. Details are currently scarce on the capability and international availability of this system.

Additional to these GNSS are a number of existing and planned augmentations systems to positional accuracy and availability on a regional basis. A good example would be the European EGNOS system and the proposed Japanese Quazi Zenith system.

4.0 GPS SIMULATION: GENERAL PRINCIPLES

The core requirements of any GPS receiver test, whether for development, integration or production purposes, is for a controlled, repeatable signal. For many tests, the signal control includes flexibility over test case, or scenario, conditions that enable performance testing at nominal and extreme or error-state conditions.

Real-world, live-sky testing has significant drawbacks which, in practice, preclude controlled testing. These drawbacks of live-sky testing include:

- An end user or test site cannot have any control over the GPS signal being transmitted
- The signals seen incident to the GPS receiver antenna are constantly changing as the GPS system constantly changes (precesses)
- There are occasional signal errors, often unknown to the receiver at the time
- Atmospheric conditions change significantly and have a significant impact on single frequency systems
- Testing at multiple geographic locations proves to be expensive

Using a GPS RF simulator enables the user to define and control all simulated parameters. Advantages of using a simulator include the following:

- Full control over test scenarios
- Repeatable
- Errors can be introduced in a controlled fashion and the way the system under test deals with each error can be optimised
- Atmospheric conditions can be modelled and even removed from the test
- Other signal effects can be controlled, such as multipath and antenna patterns
- Vehicle trajectory and associated dynamics can be modelled
- Future signals (eg. modernised GPS signals) can be generated to allow testing against new signals before the satellites are available in space.

GPS simulators can be used in various configurations enabling, for example, use of remotely generated trajectories and generation of interference signals as well as simulated GPS signals.

5.0 GPS/INERTIAL NAVIGATION

5.1 Overview

While both GPS and inertial navigation systems are susceptible to errors, the use of the two systems together allow the best aspects of each approach to be utilised, while overcoming some of the inherent weaknesses of each. Inertial navigation is particularly strong during short term and high dynamic manoeuvres, where GPS is less strong. GPS is particularly strong during open sky cruising, while inertial suffers inherent drift over time due to the open loop nature of inertial navigation sensors.

It is possible to use discreet units to build such a system (separate GPS and Inertial Navigation System (INS) units, known as loosely coupled) and then there are various deeper levels of integration of GPS and INS units, typically referred to as tightly coupled and ultra-tightly coupled. Typical applications range from airframe navigation (manned or unmanned) and attitude control to shell guidance. The illustration below shows an integrated embedded GPS/inertial (EGI) configuration:

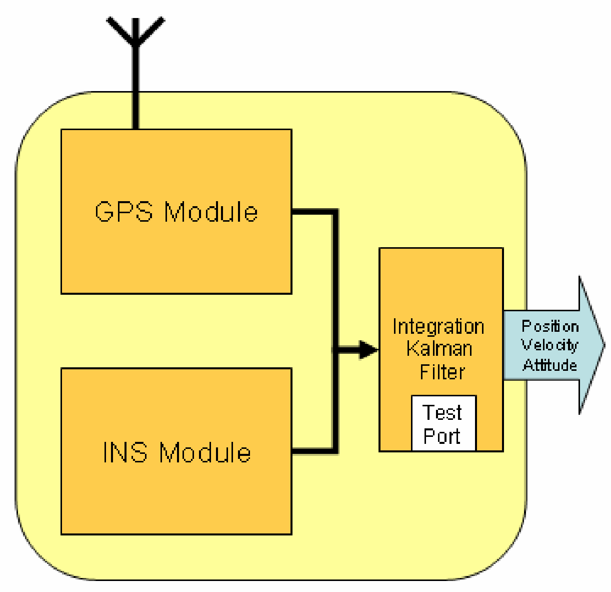


Figure 1: Example schematic of Tightly Coupled GPS/INS unit

5.2 Considerations for Testing GPS/inertial systems

Controlled testing of Integrated GPS/Inertial (IGI) systems presents major challenges. The individual sensor elements of the IGI can readily be tested using conventional test methods: an RF constellation simulator for the GPS only element, and inertial test equipment such as centrifuges and rate tables for the inertial sensors. Testing a blended GPS/inertial solution, or an ultra-tightly coupled system, requires coherent stimulation of the GPS and inertial sensors, ideally with realistic mission dynamics. Installing the equipment in an appropriate vehicle and conducting a field trial is the obvious approach, but this costly test methodology does not represent an adequately controlled test environment.

5.3 Full Simulation Approach

An alternative approach for testing operational performance of an Integrated GPS/Inertial (IGI) system is to retain the entire GPS sensor but emulate the inertial sensor. This approach has the advantage that the inertial sensors are effectively removed from the testy loop and hence there is no need to physically stimulate them. This can be achieved using a laboratory-based GPS RF Constellation simulator, such as Spirent's GSS7700 product, along with a real-time emulation of the inertial sensor outputs that are coherently generated to exactly match the simulated GPS vehicle trajectory. Typical Inertial sensor performance regarding bias and drift, for example, can be established using traditional techniques, and then represented by a sensor error model driven by the simulated motion with appropriate coefficients entered by the user. It is often necessary to provide an altitude reference for Inertial-only navigation, such as a pressure altitude input.

The key benefit of this approach is that the stimuli to the navigation algorithms, in the form of GPS pseudorange measurements made by the GPS receiver under test and the emulated linear delta-velocity and angular delta-theta inertial sensor outputs, are wholly under the control of the user and are extremely repeatable. This allows fine-tuning and debugging of the navigation algorithms across a range of operational test scenarios.

IGI manufacturers typically provide a test interface to accept this simulated inertial test data. As the physical sensors on the IGI are bypassed the simulated data is injected into the relevant navigation algorithms. This approach is therefore valid for testing the GPS interface, Kalman filter and with the possibility of hardware in the loop testing the final application of the navigational data can be thoroughly tested. In the case of discreet GPS and inertial units making up a system, it is simple to substitute the generated inertial data in place of the data from the IMU.

Figure 2 shows a typical test system configuration for such an approach.

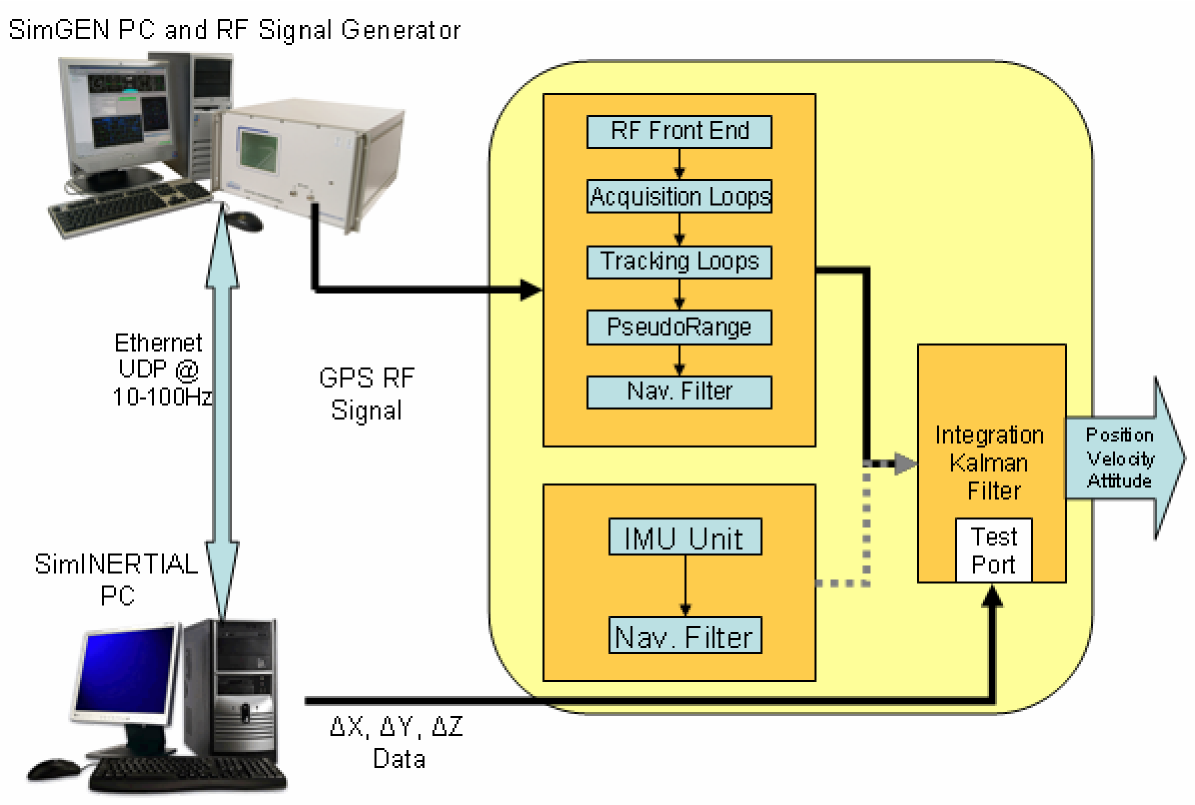


Figure 2: EGI Test Solution

The satellite constellation and vehicle motion are either defined using the SimGEN software or by using remote trajectory data. The latter could be, for example, from a flight simulator, or real-time data streamed from any other source.

5.5 Inertial Error Modelling

Using a test set up such as this it is possible to test error states as well as nominal test conditions. Physical sensors such as accelerometers and gyroscopes suffer from a complex range of imperfections that yield errors in the measurements made. In order for a test system to reproduce operationally representative sensor outputs it is necessary to apply an error model to the nominal δv and $\delta\theta$ data produced by the base simulation.

Spirent's SimINERTIAL system can make use of user-configured generic error models (for example as specified in Appendix 2 to STANAG 4572, an error model that has been derived from mature Accelerometer and Ring Laser Gyroscope designs plus recognised IEEE standards).

6.0 INTERFERENCE AND JAMMING

The ability to deny navigation service across a wide area by intentionally jamming the GPS signal with a relatively inexpensive local transmitter is of obvious concern to anyone using GPS navigation in a military application.

Due to the ease with which these jamming devices can be manufactured, it is important for any modern military relying on GPS navigation to develop systems with reduced susceptibility to a variety of jamming sources.

6.1 Field Testing For Interference & Jamming

Field testing of such devices, while an important part of any development process, is not only an expensive exercise, but also has the potential to deny service for any users in the vicinity. This method, however is more representative of the real world and can certainly be viewed as a valid test method in certain, controlled cases.

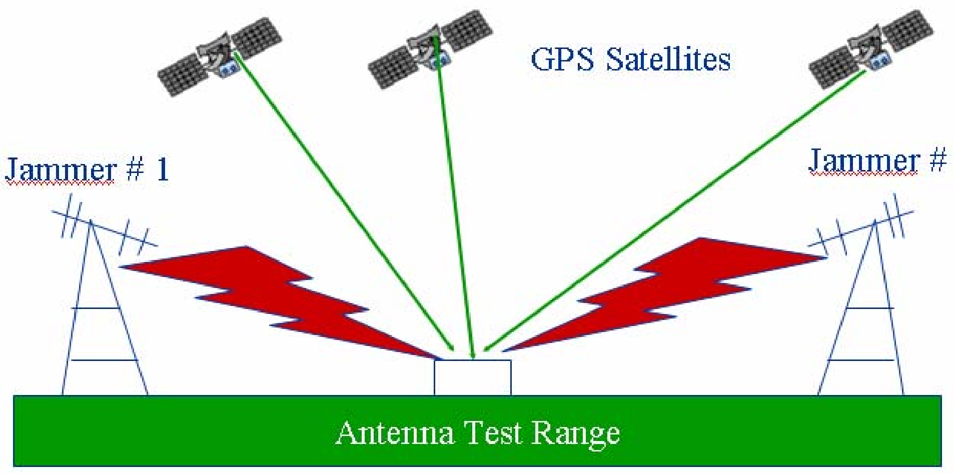


Figure 3: Receiver Field Test including Interference sources

Generating the GPS interference on a test range is not a trivial matter. The low-power GPS signals must be combined with controlled, known and repeatable levels of noise and interference. One of the problems is in order to conduct meaningful trials the test range should be free of unknown interference or noise.

Other significant disadvantages of this method are that variable effects of the weather can affect the repeatability of this method, and by it’s very nature, security concerns could be raised as the test range and setup is visible to others.

In addition to this, once the effects of motion of the platform using the GPS navigation system are introduced, not only do costs escalate, but the complications in conducting repeatable tests increase dramatically. If the test is required to include multiple interference sources, possibly located themselves on moving vehicles, the difficulties in maintaining control and repeatability increase again.

6.2 Laboratory Generation of Coherent Interference Signals

A laboratory-based system, using a GPS RF simulator can be an integral part of the development and test effort. Having the inherent control and repeatability of the RF simulator integrated with the capability to generate controlled known and repeatable interference eliminates many of the problems faced during a field trial.

Typical interference sources to be built into a test scenario are Continuous wave (CW), AM and FM, some of which can be pulsed.

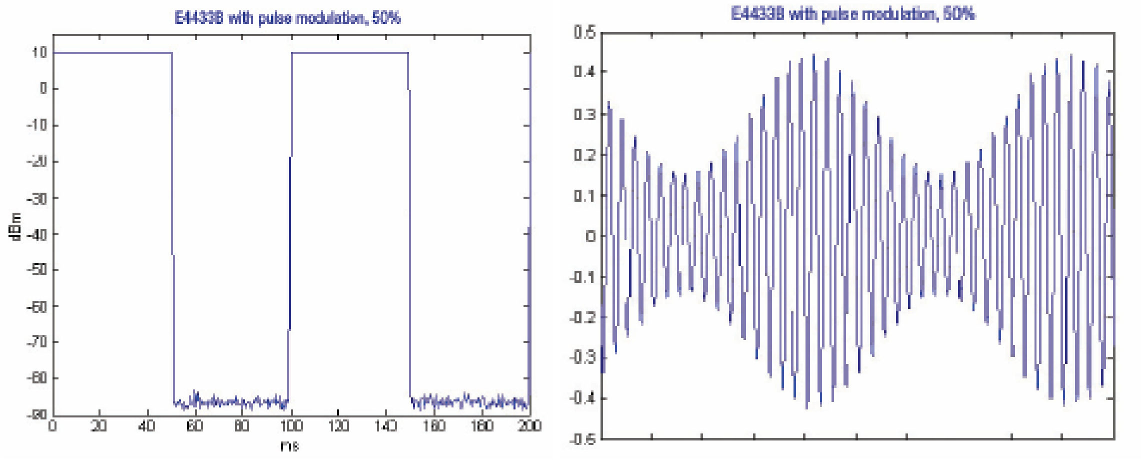


Figure 4: Typical Interference Source Waveforms

It is possible for the simulator control software to also interface with the commercial signal generator to control the signal type and frequency of the interference sources. The Spirent GSS770 unit can interface with up to 4 fully controllable interference sources per GPS signal. Due to the expandable nature of this implementation, it is possible combine GPS, Glonass and Galileo signals into a single high level output for further combination with up to 4 channels of noise per channel of RF.

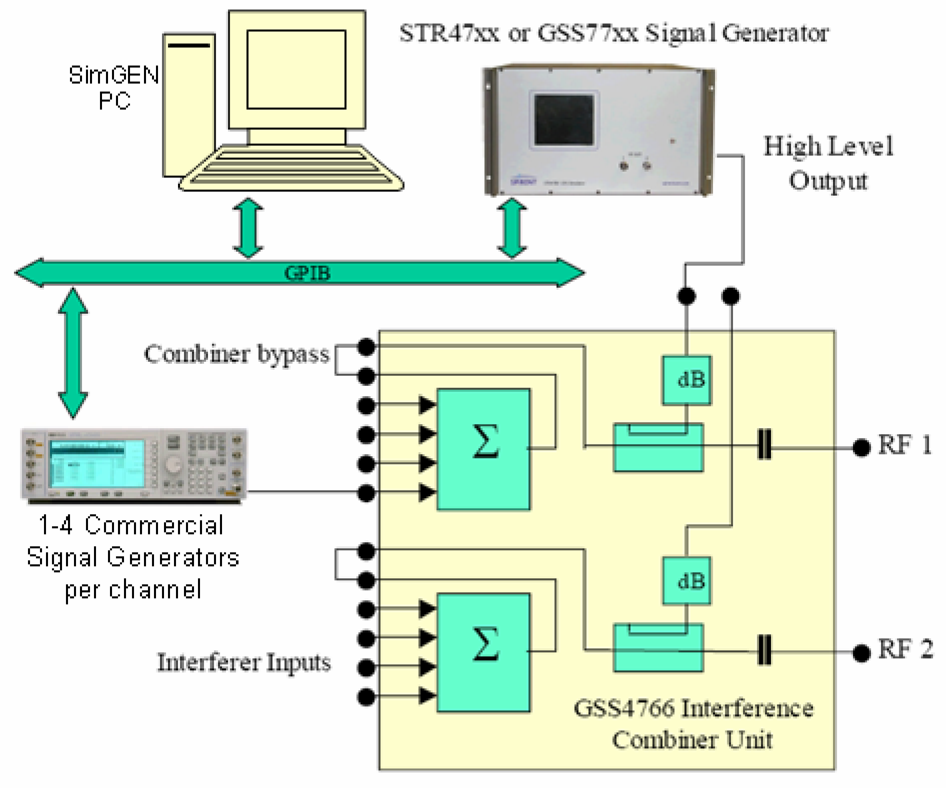


Figure 5: Interference Combiner Unit Configuration

In the case of relative motion between the GPS receiver and any interference sources, by defining the position of the interference sources in the control software, it is also possible to model the power level to be generated to create a realistic power profile relative to distance between the transmit and receiver antenna.

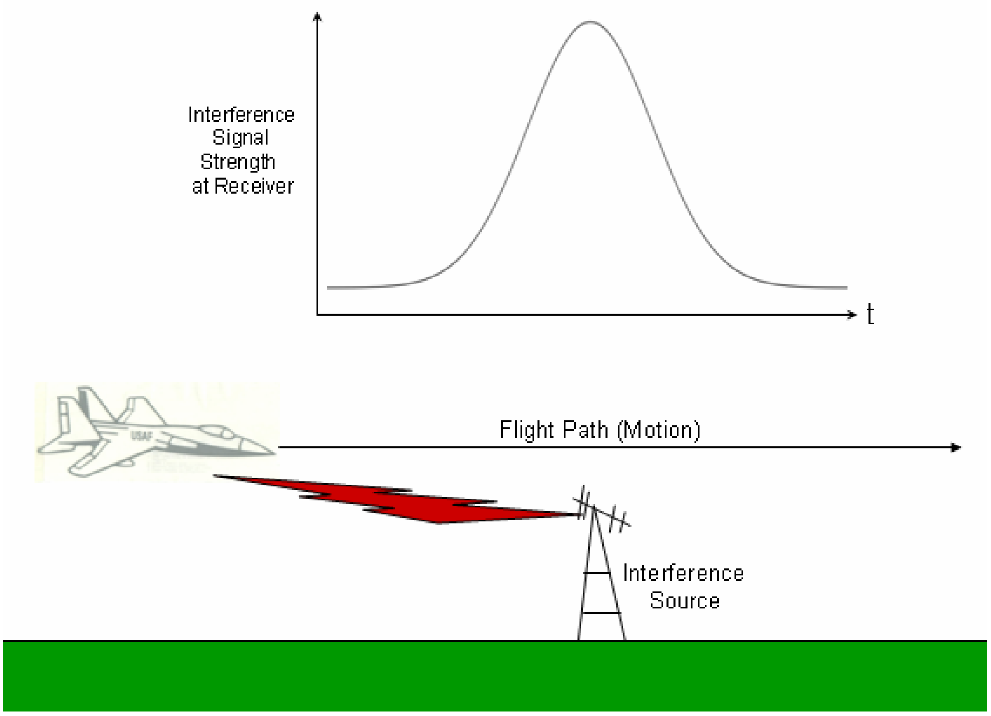


Figure 6 Interference Signal Power Modelling

It should be borne in mind that the antenna design represents some of the design effort to reduce the effects of interference, and the antenna is generally not included in a simulation environment. Modelling the antenna gain and phase characteristics can help in this regard and is recommended.

7.0 CONTROLLED RECEPTION PATTERN ANTENNA (CRPA)

One method of mitigating the effects of a localised jamming source is to develop a directional antenna that has low gain in the direction of the jamming, while maintaining a high gain in other directions in order to track the maximum number of GPS satellites. Due to the unpredictable nature of where the jamming source(s) are in relation to the antenna this must be an adaptive antenna of some description to cope with the threat at any particular time.

The currently accepted means of achieving this is the deployment of a Controlled Reception Pattern Antenna (CRPA). There are 2 classes of CRPA to achieve resistance to jamming. The first is the antenna RF method, where phase shifts cancel signals in the RF domain to achieve null steering towards the interference source. The second is space/time adaptive technique, where antenna signals are digitised and mathematical processing is used to remove the interferers. Both of these methods use multiple antenna laid out physically in an array, as shown in the following example.

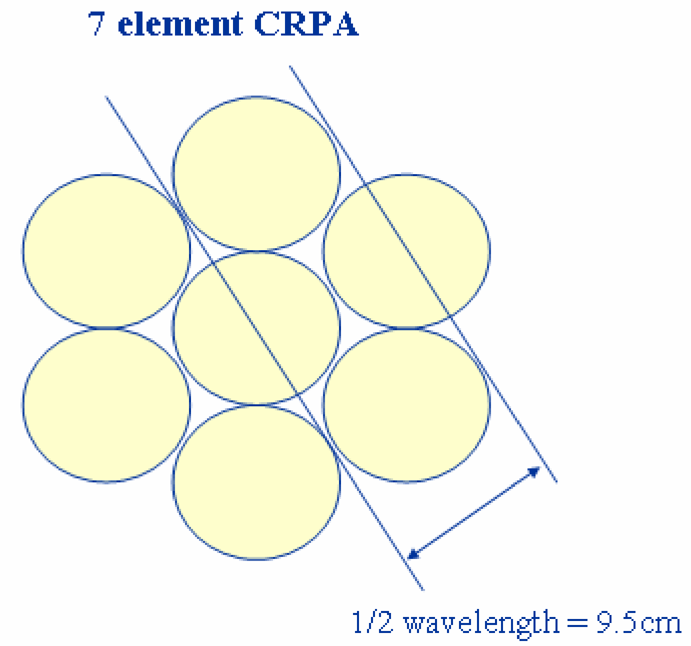


Figure 7 Illustrative 7 Element CRPA

The traditional approach to testing these devices is largely the same as with any other interference mitigation technique, requiring a test range, with the same deficiencies and problems in deploying wide area jamming and its impact on the civilian population as well as the issues surrounding repeatability and control, weather and security.

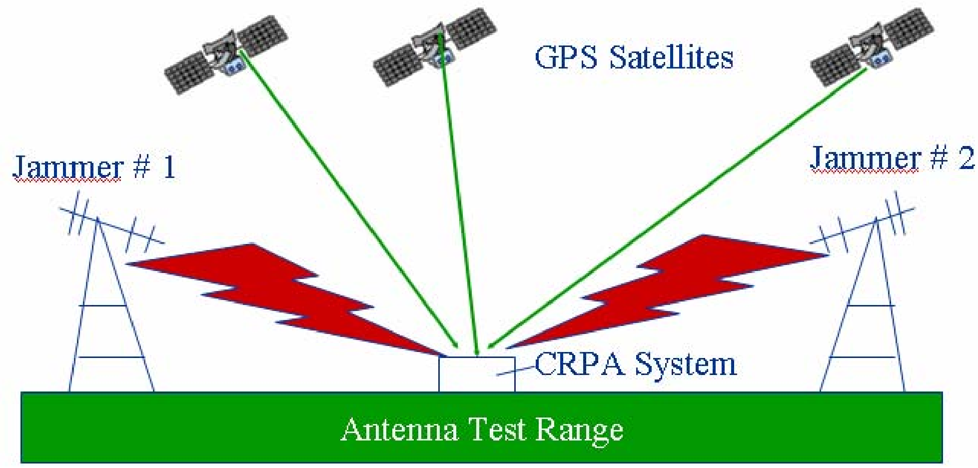


Figure 8 CRPA Test Range

There are a number of options available to develop a laboratory based system for CRPA test. A full analysis of the possible options is outside the scope of this paper. The various options are presented briefly here.

For CRPA, the antenna is the major component under test therefore an approach involving free space transmission of the GPS signal and interference is required. Due to the need to transmit the GPS and interference signals through free space while maintaining an environment free from external signals demands a shielded chamber. Further to this, the need to stop any significant reflection of these signals causing multipath errors so this chamber needs to be lined with Radiation Absorbing Material (RAM).

The very directional nature of this approach also dictates that, among other factors, the GPS signal cannot be transmitted as a combined signal from a single antenna. The signals must be transmitted individually from unique transmit antennas. The physical direction and elevation of these antennas from the CRPA should ideally match that of the relative position of the satellites in the scenario as defined in the simulator control software.

Spirent Communications has developed the GSS7790 L1/L2 GPS simulator to satisfy such a requirement. As the installation and calibration of such a setup is a particularly specialist area, a survey, install and calibration service is available and recommended.

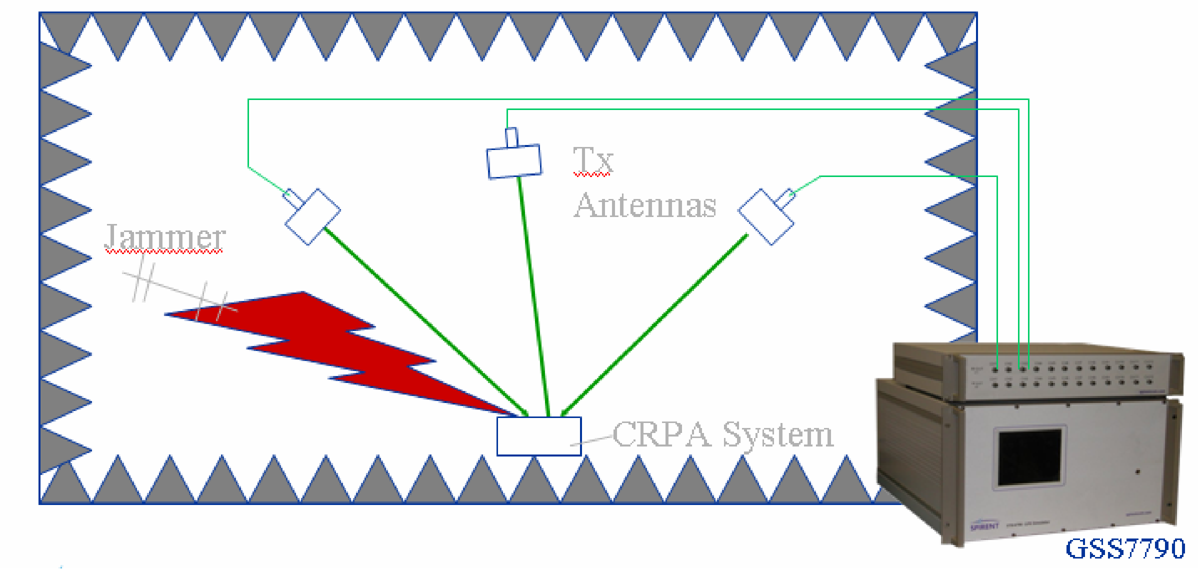


Figure 9 Chamber Approach to CRPA Testing

The chamber approach does, however have drawbacks. While the cost and availability of a chamber must be a consideration the major drawback is the difficulty in moving the test piece linearly due to the physical constraints of the chamber, hence limiting the breadth of test cases available. Other considerations are that as the transmit antennas are physically located in a fixed position, a positional mismatch will slowly develop in long scenarios. In practice, this can limit the length of the scenario that can be run.

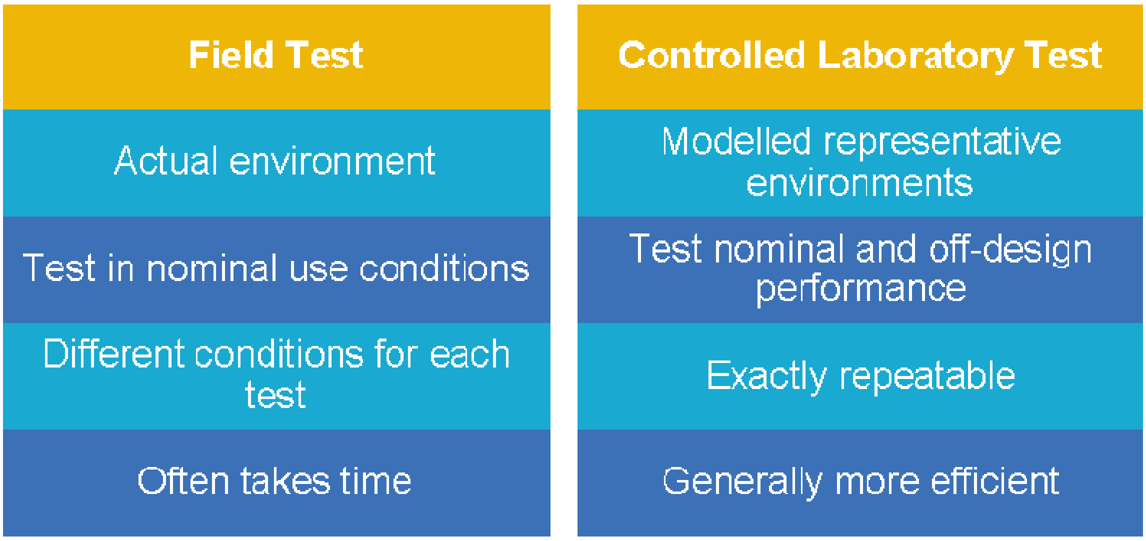
A secondary approach to developing CRPA is to remove the physical antenna from the setup and to connect via coaxial cables to the antenna inputs on the CRPA system. In this approach a simulated signal (GPS + Jamming) representing the signals incident on each element of the phased array antenna is required. Spirent has provided these systems for 7 element CRPA systems including coherent simulation of both GPS and Jamming sources. Such a test can be very effective at testing the processing algorithms of the CRPA system in a variety of controlled conditions. As with the chamber approach, this is a specialist area with particular considerations and we recommend that Spirent's advice is sought at an early stage.

In all cases, the simulated truth data is available from the simulation system via data streaming. Receiver position and related data can be captured, for example using Spirent's SimDATA package, and provided over an appropriate interface bus for subsequent analysis against the streamed truth data. In this way the performance of the CRPA system can be readily analysed and performance of the system optimised.

8.0 CONCLUSION

Thorough testing of military systems is essential to ensure that predicted or desired performance can be realised under both nominal and error, extreme or adversarial conditions.

Testing has to be carefully considered both to meet the objectives of the programme in question and to ensure that the most efficient and effective approach is used. Field testing and controlled laboratory testing both have their place in most test plans. A comparison of the considerations of each approach is presented in the following table.



Field Test	Controlled Laboratory Test
Actual environment	Modelled representative environments
Test in nominal use conditions	Test nominal and off-design performance
Different conditions for each test	Exactly repeatable
Often takes time	Generally more efficient

Figure 10 Comparison of Field and Controlled Laboratory testing

Typically, most testing would be completed under controlled laboratory test conditions. A field test may be specified to confirm laboratory test results in the actual environment.

Within the controlled laboratory environment, a wide variety of testing is possible. Test configurations are possible that include not only the simulated GPS signals but also simulated inertial sensor data, jamming and interference sources. Remote motion data and hardware-in-the-loop configurations can be readily specified and accomplished. As the test set-up is directly under user control, and repeatable, testing is generally efficient and device performance can be readily characterised and optimised.

Advanced configurations for coherent stimulation of adaptive antenna arrays with both GNSS and coherent interference sources are feasible and have been implemented in the field by Spirent.