Spirent Communications

Certification Requirements and the Status of GNSS RF Simulation Systems

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NAV 08

Royal Institute of Navigation

Land Air Sea Space

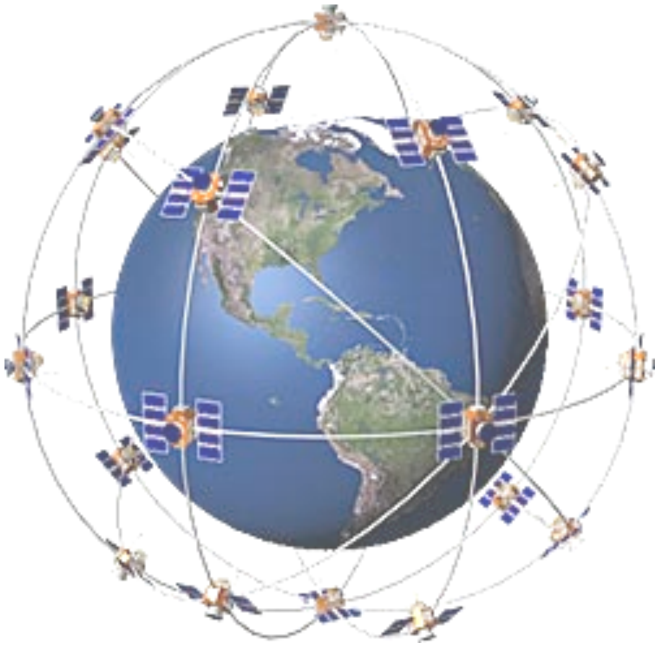
Inspired Innovation

Agenda

- GNSS RF Simulation explained
- “Certified” in the context of a simulator
- Simulation as a standard methodology for certification
- Simulation proved and accepted
  - Examples of key programmes relying on RF simulation
- Moving on with certification standards

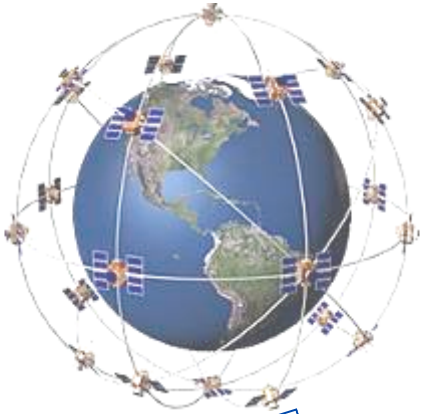
What is GNSS RF Simulation?

- Representation of a GNSS receiver's environment on a dynamic or static platform by:
  - Modelling of the platform motion
  - Modelling of the satellite motion
  - Modelling of atmospheric effects
  - Modelling of signal effects and errors
  - Exact implementation of relevant ICD
  - Modelling of GNSS system errors

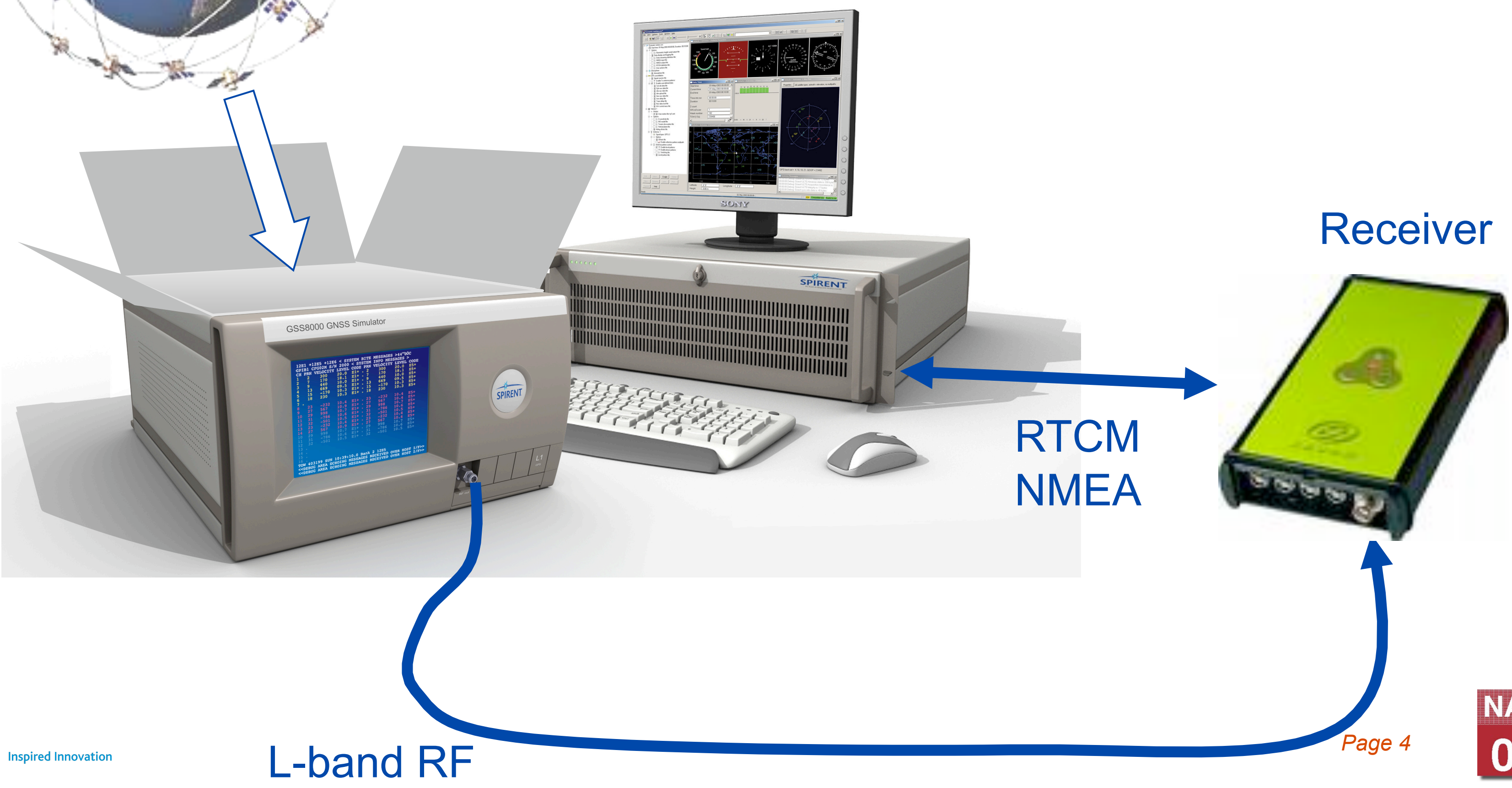


Generation of accurate facsimiles of the signals as they would be received from an **actual orbital constellation of satellites**, that are used to stimulate a receiver

What is GNSS RF Simulation?



Your constellation (GPS, GLONASS, Galileo signals), your motion, your atmosphere, your errors, your navigation data under your control



What simulation is not

- Simulation does not replicate the real world precisely
- Exact real-world replication is undesirable because:-
  - The real world has too many unknowns
  - It is not at all repeatable
  - Not flexible - we can't ask for satellites to be turned on/off, or command the atmosphere to *"be gone"!*
  - For these reasons, real world replication is **not** what is needed for certification, qualification or type-approval testing

- Controlled, repeatable ***representation*** is the requirement for certification and related testing
- A Simulator provides this capability, as its test signals/ scenarios are completely repeatable and as laboratory equipment, its performance is readily quantified/calibrated

Alternatives to simulation

- Live sky
  - Too much variability and unknowns to be relied on for more than the most basic, unqualified 'quick check' tests. Certainly not suitable where measurement accountability is required.
  - Not possible where GNSS space segment is not deployed!
- Radiated outdoor test ranges
  - Provide limited test capabilities
  - 'Constellation' is fixed and limited – not truly representative
  - High capital cost, hire fees, travel
  - Signal distortion due to proximity of terrain along entire length of signal path is not representative of a real GNSS system
  - Still subject to local uncontrollable environmental variability (weather, RF interference)
  - May be acceptable for certain limited tests, but not certification, which demands a much higher test integrity.

Simulator verification

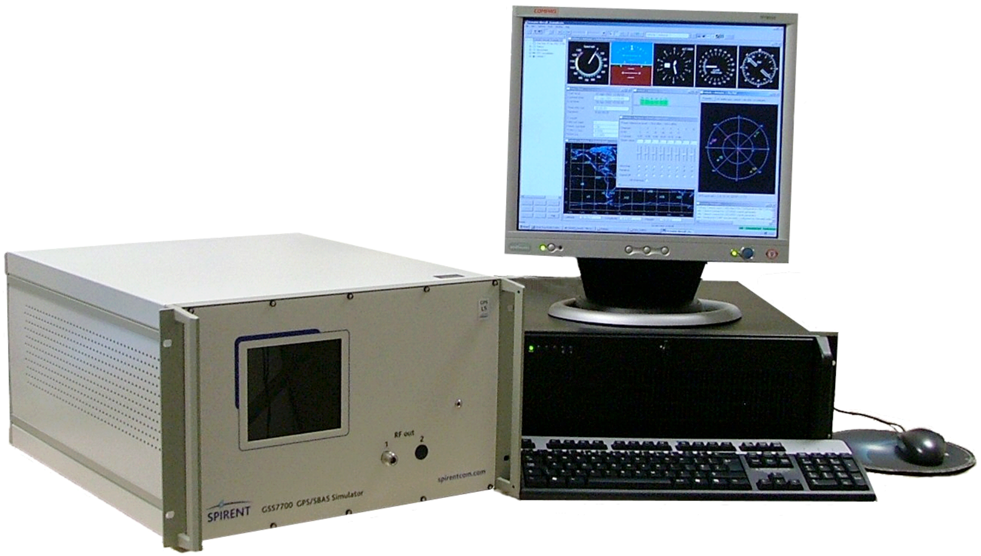
- There are currently no standardised methods for certifying a simulator
- However, this paper gives evidence of how it has been/can be done in the absence of any prescribed method
- It also shows that a simulator can be validated as a tool for subsequent certification testing

Case studies - Galileo Certification

- Contracted by ESA to supply Simulation systems for
  - Certification of Ground Receiver Chain (GRC)
    - Must be in place prior to the Galileo IOV phase
  - Certification of Test User Receiver (TUR)
- Complex systems supporting
  - PRS-GRC
    - L1-B/C BOC(1,1) and PRS at L1-A, plus E6-B/C PSK and PRS at E6-A
  - Non PRS-GRC
    - L1-B/C BOC(1,1) and PRS-Noise at L1-A, plus E6-B/C PSK and PRS-Noise at E6-A, plus E5ab ALTBOC 8-PSK
  - Non PRS/PRS-GRC and TUS
    - As above but with full PRS-capability reinstated at L1-A and E6-A.

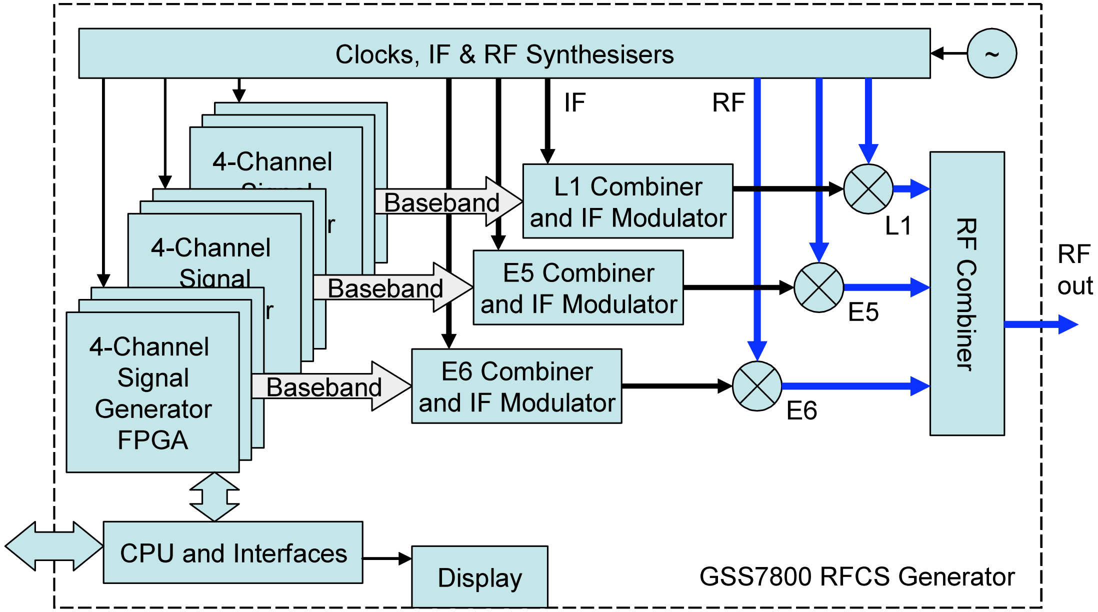
Case studies - Galileo Certification

- The GSS7800 RF Constellation Simulator **(RFCS)** was developed on Spirent's proven, top-of-the-range GSS7700 GPS RFCS platform
  - This enabled the fast-track programme timescales to be met
  - and reduced risk to the programme



RFCS Signal Generator Architecture

- Digitally Intensive
  - FPGA Base
- High Stability, Low Noise Internal Reference
- IF Modulation from Baseband I/ Q
- Modular
  - # of Channels
  - # of Carriers
- L1-A/B/C, E5ab, E6-A/B/C
  - Up to 16 satellites in view on each carrier
- Compatible with Spirent’s GSS7700 GPS Simulator
- Multipath Fader
  - per channel
  - 4 separate reflection paths
- Built-In Test Equipment



Verification of the RFCS is essential

- **The Challenge**
- Verifying Conformance to SIS-ICD and Performance when:
  - The signals are nominally below the thermal noise floor
  - Certified, proven Galileo receivers do not exist
- **The Solution**
- Use standard test equipment for regular measurements
  - Logic & Spectrum Analysers, Counters, ‘Scopes, Power Meters
- Use novel and innovative techniques to transfer measurements into domains where standard test equipment can be used
  - PM-AM Demodulators, Virtual Instruments, Mathematical Analysis

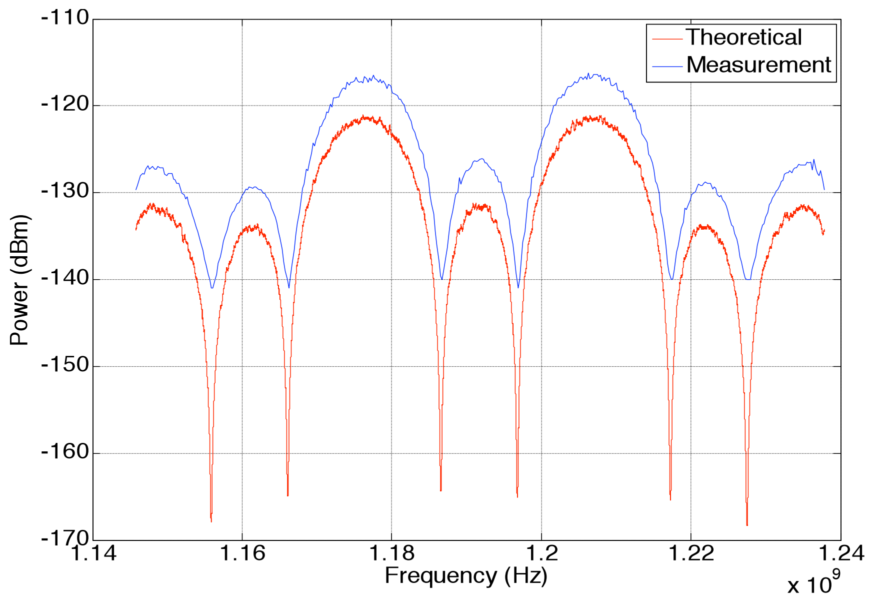
RFCS Verification Principles

- Method A: Visual **Inspection**
  - Size, Weight, Connectivity, etc
- Method B: **Demonstration**
  - Feature set, functions, GUI operation and so on
- Method C: Deterministic **Measurement**
  - Parametric performance
- Method D: Mathematical **Analysis**
  - Derivation of performance where deterministic measurement is not possible or inaccurate.

RFCS Verification tests

Signal modulation and bandwidth

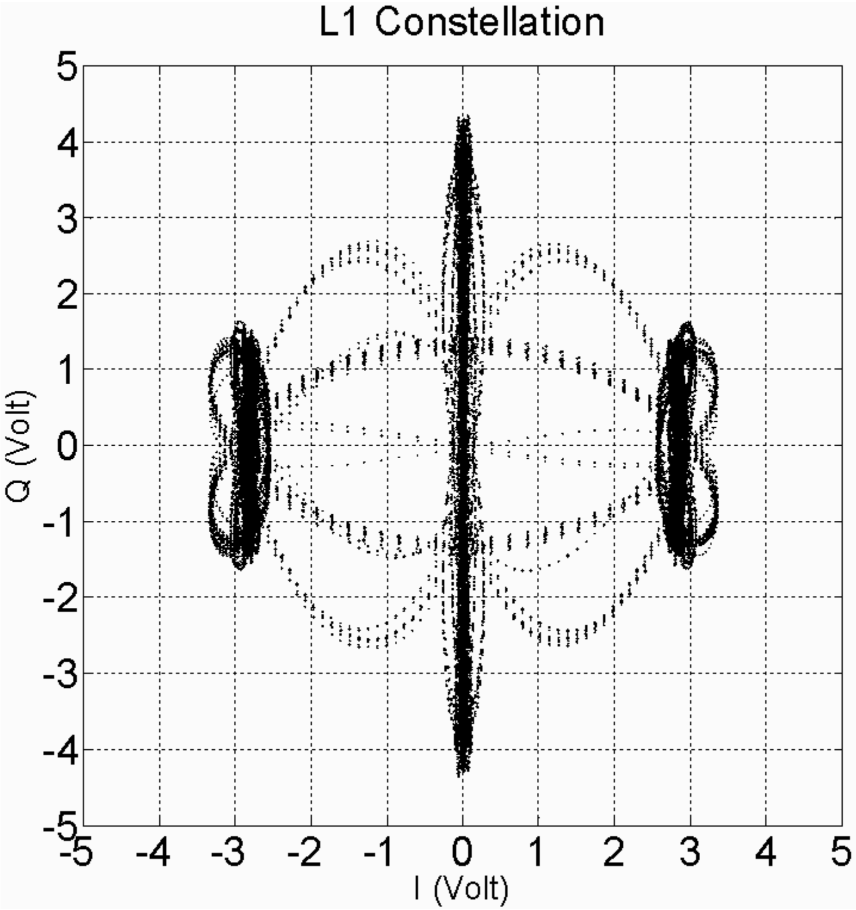
E5ab shown

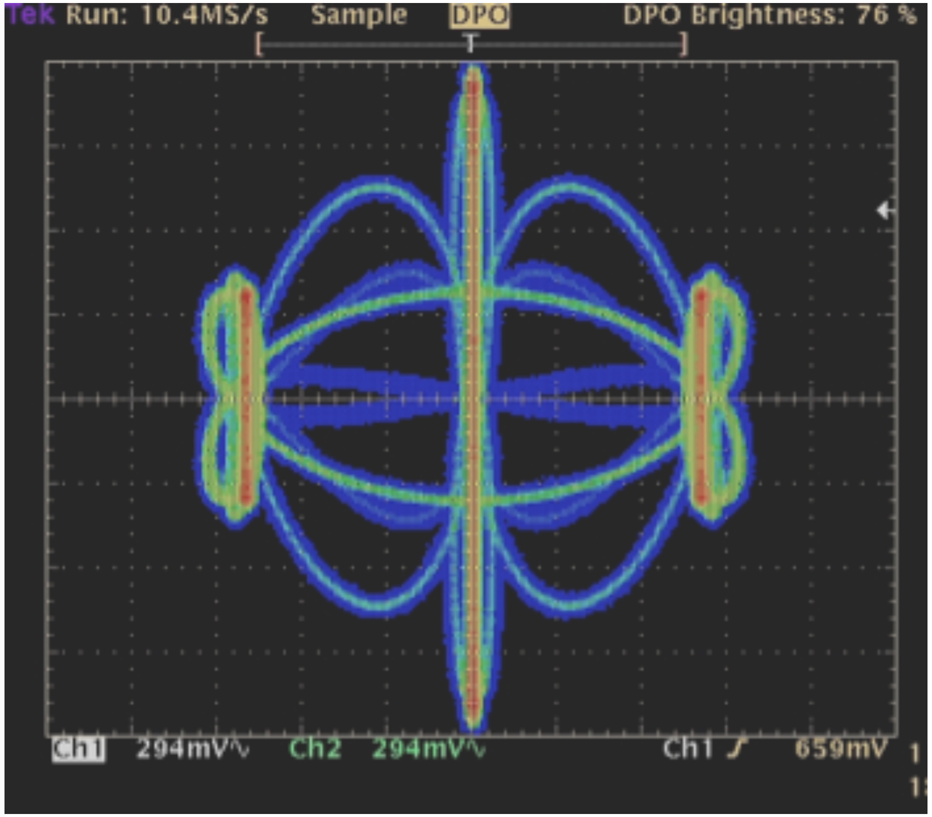


- The High degree of correlation between theoretical and measured indicates:
  - Correct modulation envelope
    - Multiple signals per carrier
  - Correct bandwidth
    - Digitally controlled
- Theoretical vs measured modulation: Visualised by Agilent's SystemVue™ using the SIS-ICD mathematical description

RFCS Verification tests

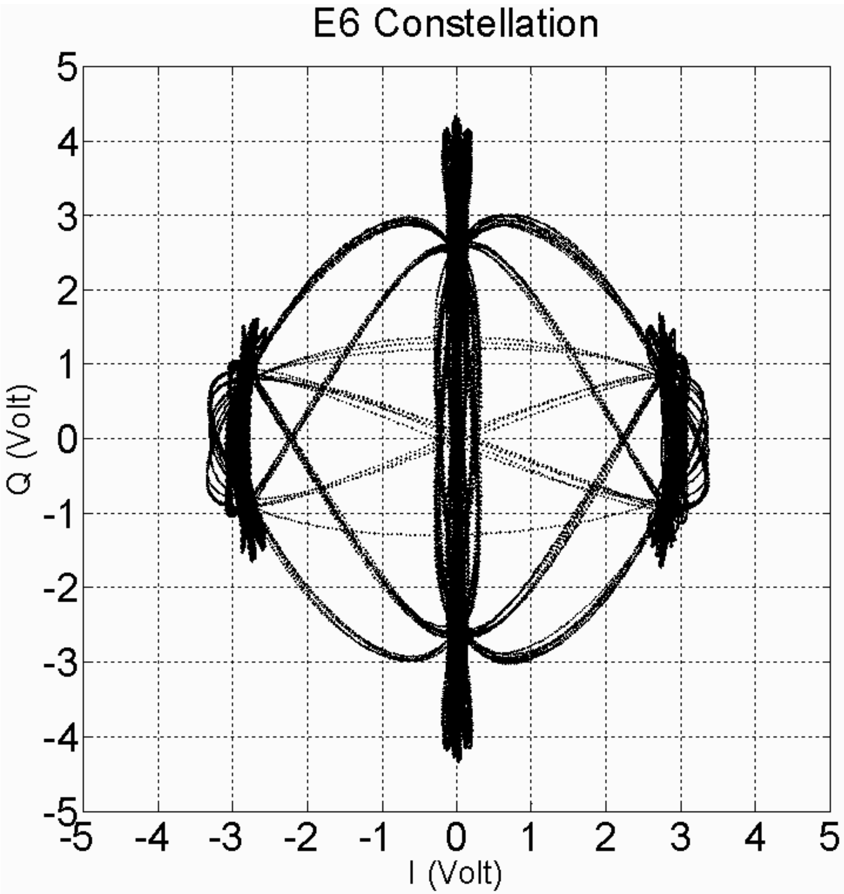
- L1 theoretical versus actual measured

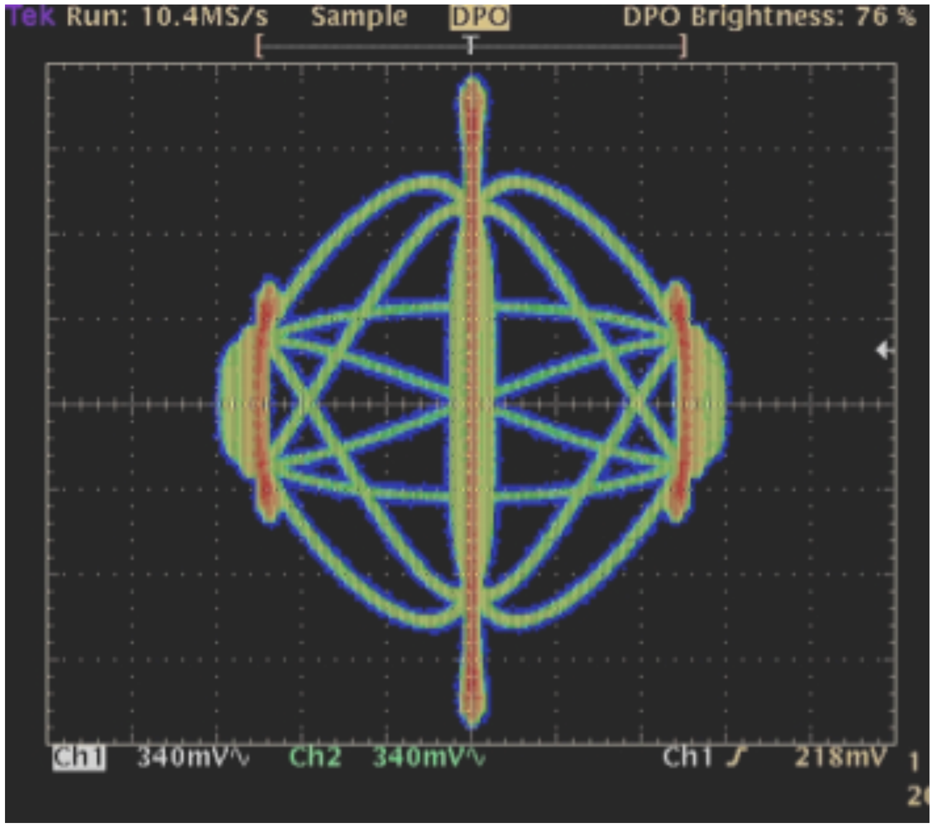




RFCS Verification tests

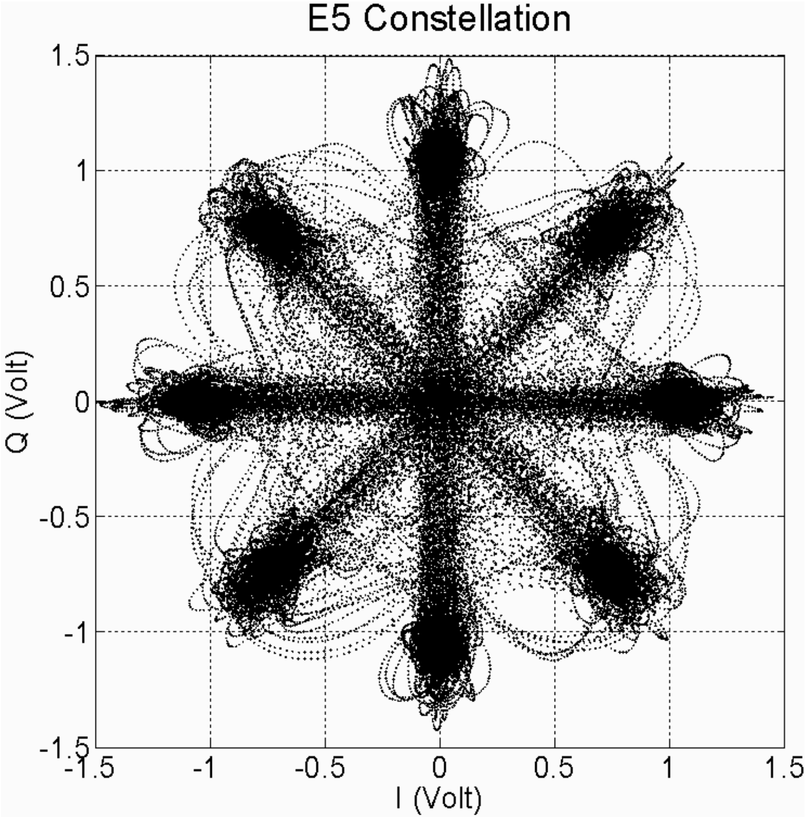
- E6 theoretical versus actual measured

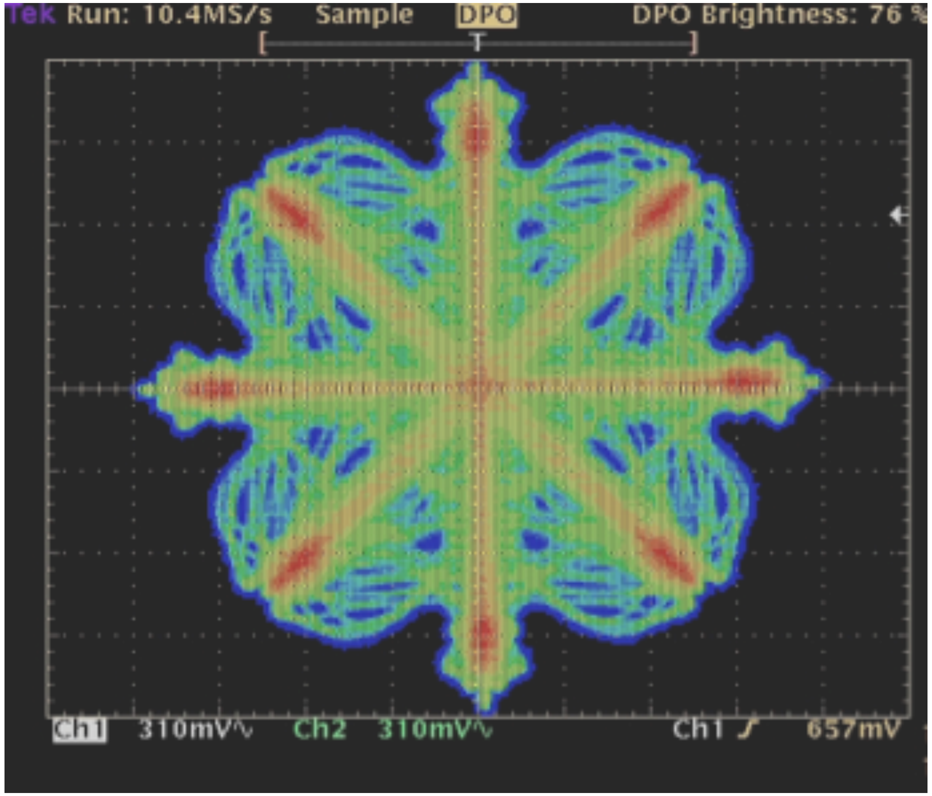




RFCS Verification tests

- E5 theoretical versus actual measured





RFCS Verification tests

Demodulating Signal Content PM-AM

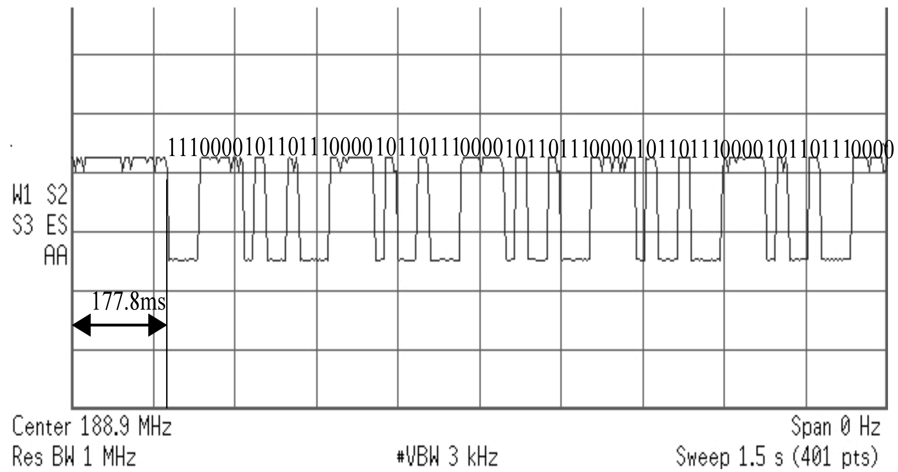
Use the Signal Generator itself to perform correlation function on the Phase Modulated signals

- Run simulation with two coherent channels
  - Two co-located, identical satellites
- On First channel include all content
- On Second channel remove only content of interest
- Resultant signal combination leads to Amplitude Modulation caused by the difference element alone
  - PM-to-AM translation
- Use AM detector to capture element of interest

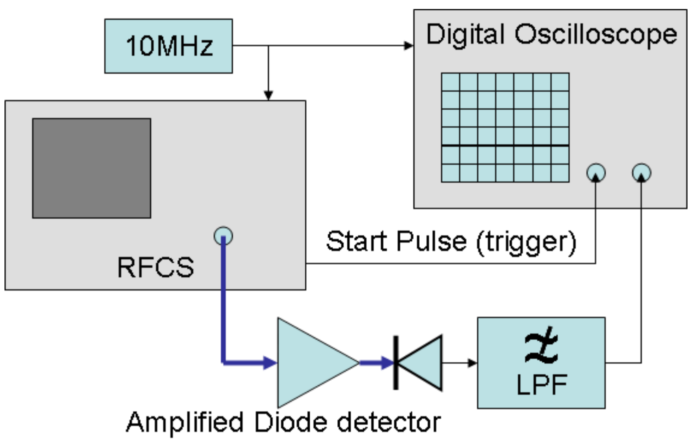
RFCS Verification tests

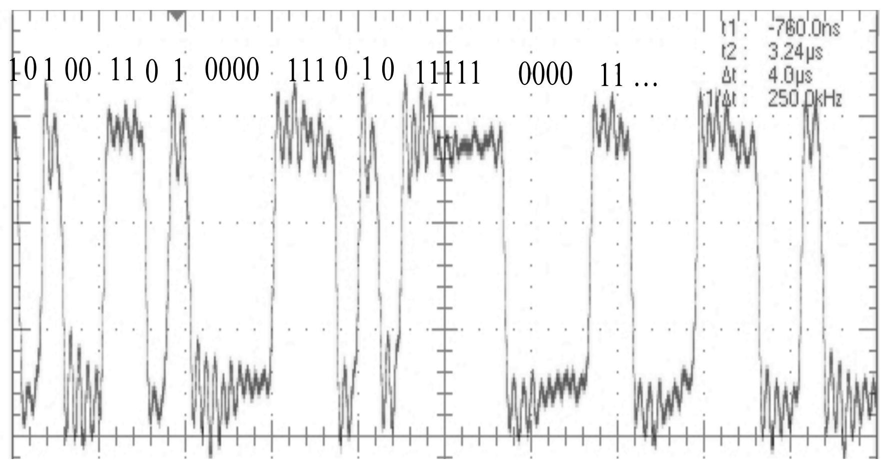
Two AM Detector Methods used

- Spectrum Analyser
  - Tune to carrier frequency
  - Set frequency span to ZERO
  - Set sweep speed to view demodulated data
- Diode Detector + Oscilloscope



FNav Symbols at E5a using Spectrum Analyser



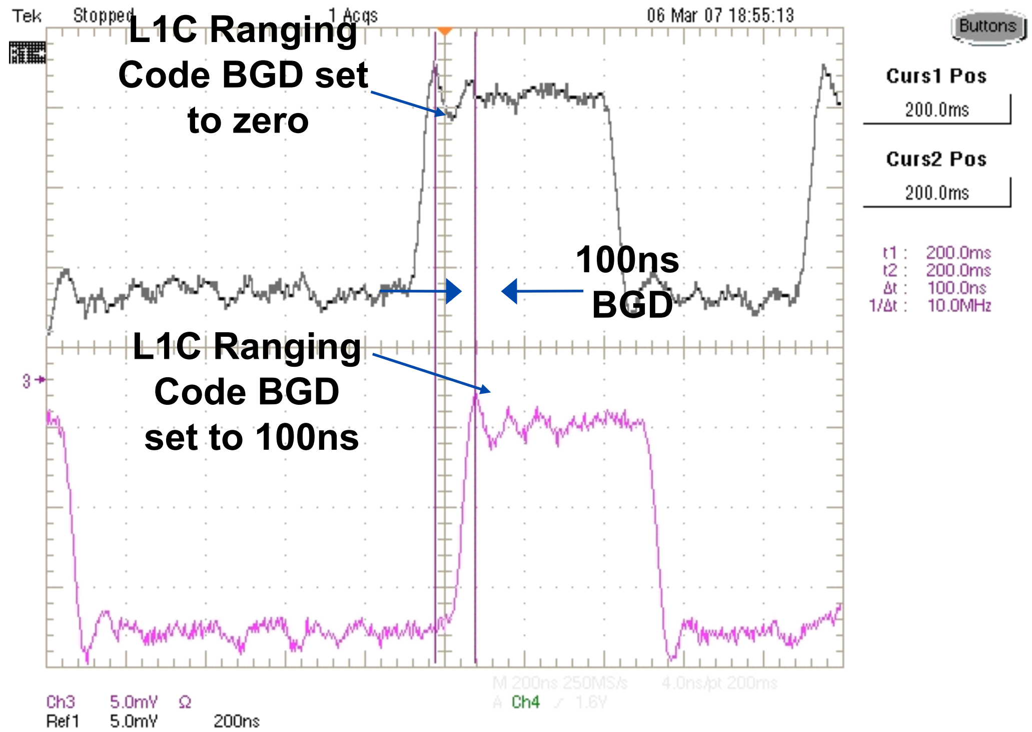


E5aI Code using Diode detector + Oscilloscope

RFCS Verification tests

Broadcast Group Delay (L1C example)

- PM-AM Diode-based Demodulator
  - RFCS issues a start pulse which triggers oscilloscope
- Upper trace shows the result when the BGD = zero
- Lower trace shows result of second run where the BGD = 100ns
- Measured Difference is in full accordance with the requested value



RFCS Verification tests

Many more tests including:-

- Ionospheric delay – NeQuick model
  - TEC calculated from user-supplied coefficients = measured TEC
- Code-carrier dispersion at E5
  - Dispersion due to wide bandwidth AltBOC signal correctly applied
- 1PPS accuracy
  - +/-500 ps 1PPS to RF code phase transition required – verified by 40^{th}-order polynomial and High-Speed scope capture
- Signal stability
  - <75ps inter-signal stability between like signals from different satellites over 24 hours

RFCS Verification tests

Conclusions

- The verification test procedures, without the use of a Galileo receiver, were conducted on fully representative RFCS units and occupied 5 months of intensive activity
- All the tests were pre-approved by the customer and many were conducted in his presence
- The resulting test report extends to over 250 pages plus supporting data
- **The verification activity has proven the suitability of the RFCS (RF Constellation Simulator) to be used for In-Orbit-Verification Receiver certification across all Galileo frequency bands and services.**
- For more information see comprehensive paper *"Galileo RF Constellation Simulator – Design Verification & Testing"*, P. Boulton, A. Read, R. Wong, Spirent Communications PLC, Paignton, UK

RFCS Verification laboratory

- New facility in Paignton, UK devoted to customer verification
  - Unique customer system configurations can be replicated in the lab to enable diagnostics to take place

SPIRENT Communications Inspired Innovation

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Key programmes

- The Galileo GRC/TUS Certification is just the latest in a history of key GNSS programmes that have relied heavily on Simulators
- The following are examples of other programmes where simulators play a crucial role.
- Collectively these demonstrate the suitability of a simulator as a reference tool for certification by showing that:
  - The relevant SIS-ICD is correctly implemented in the simulator, and receivers designed and tested using simulators then go on to perform equally well in real world applications.
  - Core methods and algorithms have been proven across a huge customer base and dozens of application areas

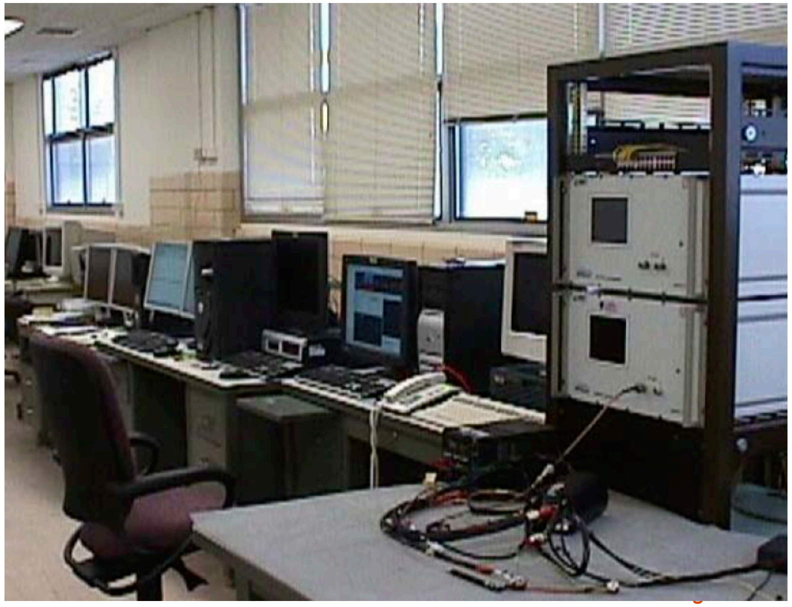
USNO GPS Timing – *did you know?*

- The Master reference receivers for the entire GPS system are calibrated using simulators at the US Naval Observatory
- Calibration of the actual simulator has given very repeatable results over a period of several years
- The USNO conclude that "Calibrations of GPS timing receivers using advanced GPS Simulators have the potential to achieve nanosecond level absolute time calibration accuracies"

"Absolute Time Error Calibration of GPS receivers using Advanced GPS Simulators" [E. D. Powers, M. Miranian, USNO, Washington DC]

NASA mission planning

- Spirent 4-output attitude-determination GPS simulator system used at NASA Goddard Space Flight Center
- Hardware-in-the-loop simulations of combined GPS+INS are used to plan trajectories for launch vehicles and satellites
  - The long-running STS programme (Space Shuttle) is one example
  - Interestingly, GPS SV launches and orbit insertions are planned in this way too!
- Other programmes that rely on this facility include:
  - Auto Flight Safety
  - Sounding rockets/balloons



Airbus A380 and A400M

- Airbus use Spirent GSS7700 simulators with GSS4150 LAAS signal generators in their A380 and A400M flight simulators
  - Hardware in the loop, real-time control of flight navigation systems
  - Also used in the development of flight navigation systems



GPS-WING (JPO) certification

- Spirent Simulators certified by a dedicated test programme called the Enhanced Validation Test Plan (EVTP)
  - An exhaustive series of tests was run to determine the fidelity of simulation against a known good set of real-world data. The simulator completed the tests successfully without reservation or restriction
  - GPS JPO Security Approval was obtained for simulating SA/A-S capabilities on a Spirent simulator
  - Security Approval for meeting all the requirements for Modernized User Equipment (MUE), including the new SDS M-Code capabilities.

"An Initial look at Validating GPS Simulators through the Enhanced Validation Test Plan"

[Proceedings of the 2001 National Technical Meeting of the Institute of Navigation, January 22 - 24, 2001]

Important points

- In the past, expensive mistakes have been made by basing testing programmes on live sky or inappropriate test methods
- With certification, especially for SoL applications, we can't afford to make such mistakes
- A reliable, repeatable, easily validated test method is essential
- It is clear from these examples that simulation testing is a credible, accountable and verifiable means of certifying navigation systems and equipment
- We must start to develop international test standards for certification and type approval of Galileo receivers & systems that benefit from the integrity of simulator testing

Voluntary Certification

- As a fundamental test tool, a simulator may need to be certified itself for certain applications
- With no clear precedent in this area, Spirent are investigating having their simulators voluntarily certified by an external approved certification body
  - (Probably the GSS8000 GPS/Glonass/Galileo system that you will have hopefully seen on our exhibition stand)
- This will verify that the simulator reproduces signals accurate to the relevant SIS-ICD, and that the signal environment modelling is appropriate for receiver testing.

Where do we go from here?

- Organisations that must certify their Galileo products to standards will insist that the test methods are:
  - ✓ Un-ambiguous & repeatable
  - ✓ Fair and uncompromising
    - Manufacturer A's equipment must be subjected to EXACTLY the same conditions as manufacturer B's (impossible with live-sky testing)
- This is already happening
  - IEC 61108-3 Galileo receiver equipment test standard for maritime applications is being drafted now by IEC TC-80
    - New standard relies almost completely on simulator testing
  - RTCM-SC104 Standard for test of EPIRB and PLB beacons
  - In both cases, test scenarios have been/will be developed, allowing all manufacturer's equipment to undergo identical stimulus

In Conclusion

- Now is the time to be developing certification test standards incorporating carefully designed simulator test scenarios
- Simulator tests and simulators themselves may need to be verified by the appropriate authorities, and this process also requires development
- Test standards will then provide a firm benchmark of quality to which all receiver manufacturers will have to test
- In turn, this will ensure that GNSS community can move forward with commercial and safety critical services and equipment that is fit for purpose
- Spirent is ready to offer its 20+ years of GNSS test experience to help develop the required test methodology to support certification activities – *please talk to us*

www.spirent.com/positioning

Thank you!

Stuart Smith

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Spirent Communications PLC is a British company,

Its GNSS simulation division has been based in Paignton, England for over 20 years.

www.spirent.com/positioning