Experimenting Galileo on Board the International Space Station

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Outline

- Overview of the Project
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  - L1/E1 and L5/E5a Visibility, Dynamics and Link Budget
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- Conclusions and Way Forward

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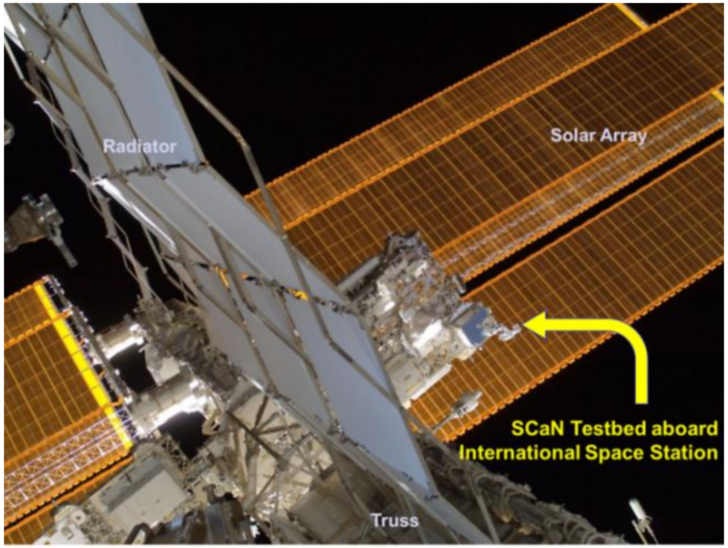
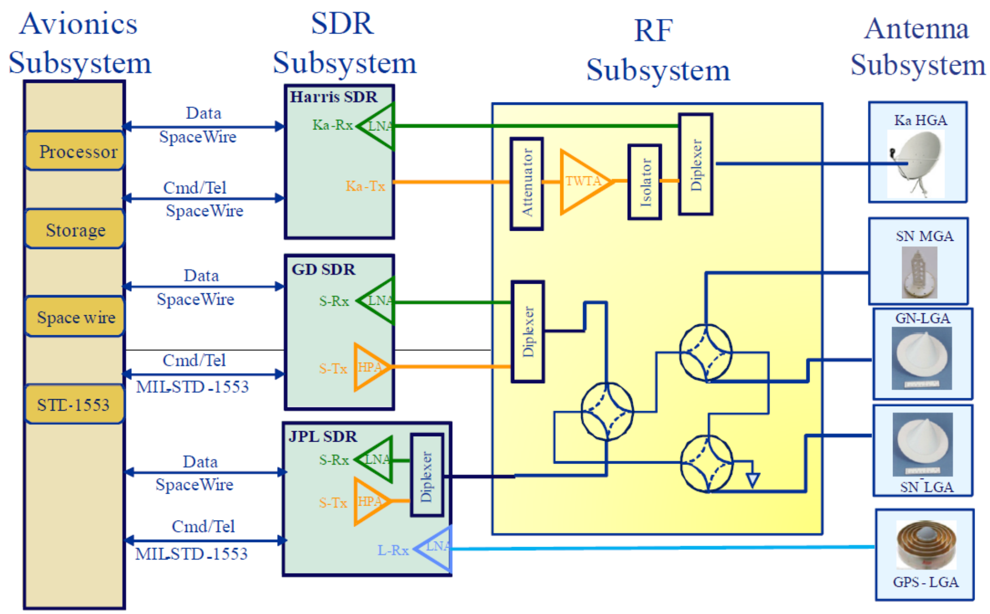
Overview of the Project Objectives

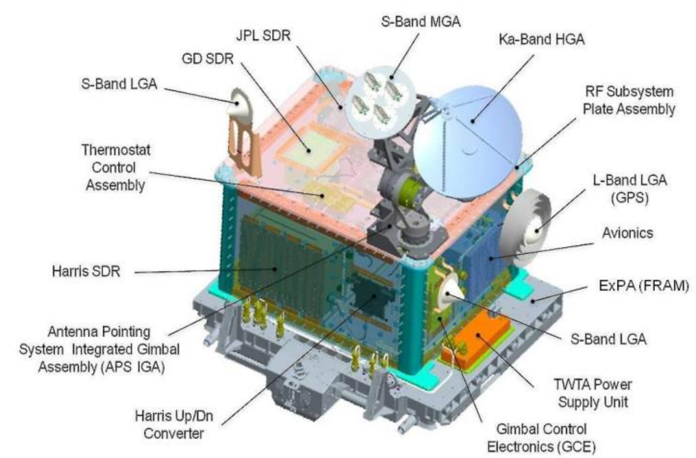
- The GARISS (**GA**lileo **R**eceiver for the **ISS**) project is an element of the overall ESA-NASA cooperation,
  - Started in mid 2016
  - Main Objective is the development of a Galileo and GPS multi-constellation waveform (Software and Firmware)
- **Project Steps**
  - Design and Development of the Galileo/GPS waveform for the SCaN Testbed (L1/E1 or L5/E5a)
  - Qualification and test the Galileo/GPS waveform using “ground systems” available at the NASA Glenn Research Center (GRC)
  - Perform in-orbit validation and experimentation (Rx Perfomances and POD)



Introduction of SCAN Testbed Architecture

- **SCaN (Space Communication and Navigation) Testbed**
  - Flight System and Ground System
  - Launched and Installed in 2012
  - 3x Reconfigurable and Reprogrammable SDRs for communication and navigation experiments (S-Band, Ka-Band, L-Band)
- **Communication with Ground:**
  - Primary Link: through the ISS S-band links.
  - Experimental Link: through the Space Network (SN) – S-Band / Ka-Band - and the Near Earth Network (NEN), S-band.





JPL SDR (L Band Components)

- **JPL SDR** is used for the GARISS experimentation
  - **GNSS Antenna:** Dorne & Margolin DMC146-6-1 passive antenna with a choke ring.
  - **Front End:**
    - direct sub-harmonically sampling L1/E1, L2 and L5/E5a GNSS Bands (1 bit)
    - the front end performs the analog to digital conversion at a clock rate of 38.656 MHz.
  - **SDR Platform:**
    - 2x FPGAs: Xilinx Virtex 2
    - Baseband SPARC processor supporting an RTEMS operating system

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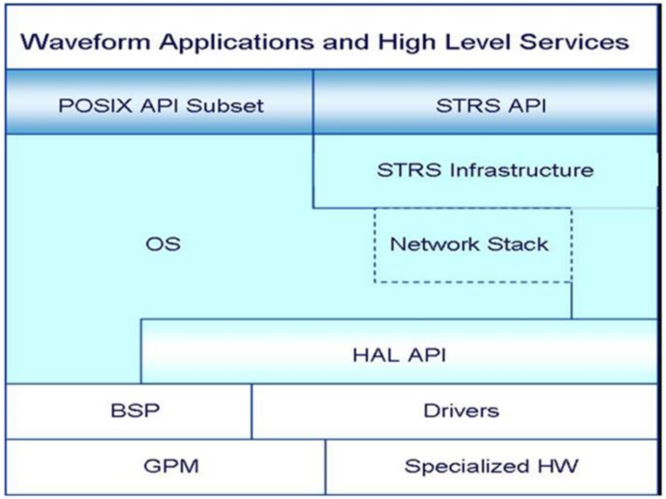
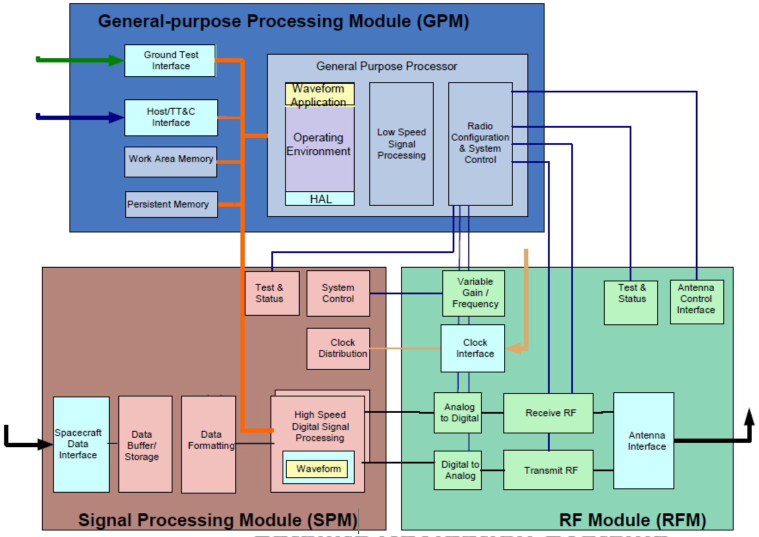
STRS Development Framework

- **STRS Architecture:**
  - **OE Middleware**
    - Abstracts the SDR hardware (Front End, FPGAs…)
    - Manages TT&C, TM,
    - Load / Unload, Execution of the Waveform
  - **Waveforms**
    - Access OE functions through POSIX APIs
    - Access the HW to STRS APIs
- The SDR Signal Processing HW is organized in:
  - **Signal Processing Module (SPM)**: high rate Waveform application components
  - **General-purpose Processing Module (GPM)**: low rate signal processing Waveform component and the managing SW.





and Security

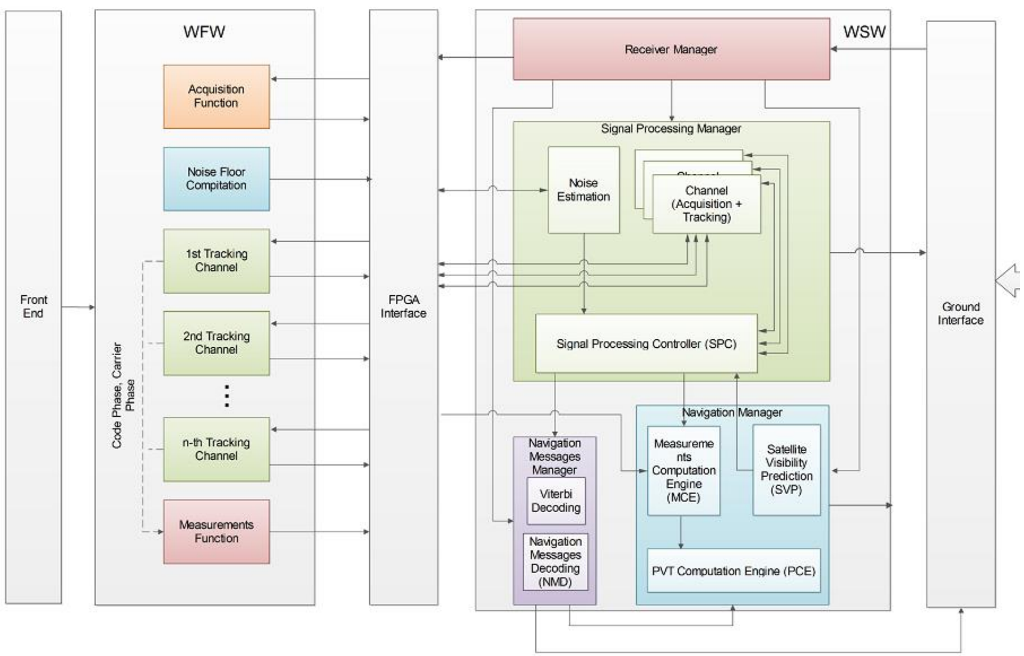
Preliminary Galileo Waveform Design

Main Components

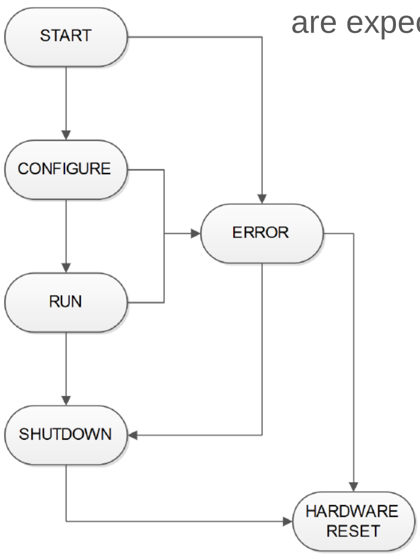
- Waveform Firmware
- Waveform Software
- Ground Monitoring and Control SW

Interfaces with the Ground

- **Configuration Interface:** (XML Based): processing configuration, aiding data, GGTO
- **Telemetry Interface:** (Binary) tracking, navigation message and PVT data. Different levels of granularity are supported. Max 150 MB of data per day are expected.



Architecture



State Machine

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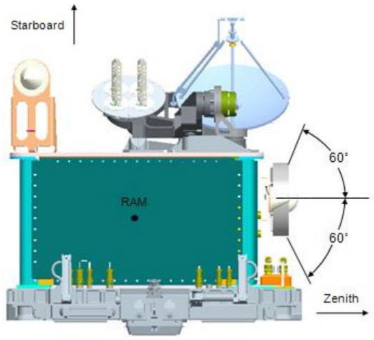
Trade-off L1/E1 vs L5/E5a

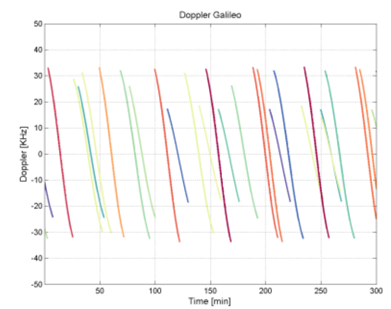
- **Visibility Analysis, Assumptions**
  - GPS Constellation Status in mid-2017 (31 SVs L1, 12 SVs L5)
  - Galileo Constellation Status in mid-2017 (16 SVs E1, 15 SVs E5a)
  - SCaN testbed L band antenna field of view is above 30 degrees
- **Visibility Analysis, Main Conclusions**
  - L1/E1: PVT Availability > 99%, Average Time Four Satellites (6 hr)
  - L5/E5a: PVT Availability is 64%, Average Time Four Satellites (12 min)



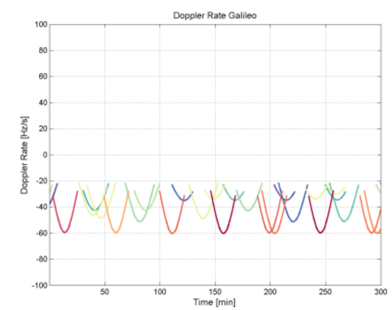
Parameter	GPS L1CA	Galileo E1	GPS L5	Galileo E5a
Average Visibility Time	20.6 min	20.1 min	20.29 min	20.07 min
Average Number Of Visible Satellites	4.9	2.23	1.66	2.18
PVT Availability	92.5 %	12.41 %	0.37 %	11.34 %
Average Time Four Satellites	28.35 min	4.47 min	54.1 sec	4.67 min

Trade-off L1/E1 vs L5/E5a

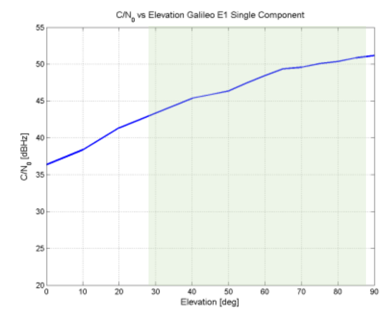
- **Doppler and Doppler Rate analyses**
  - Max Doppler Observed **±36 KHz**
  - Doppler Rate **-20 Hz/s to -70 Hz/s**
- **Link Budget**
  - CN0 (30 deg) **~ 45 dBHz**
- **Trade-off Conclusions**
  - Final Choice for the L5/E5a Band
  - <u>Cons</u>: Less LOS, Lower PVT Availability, Higher FPGA resources, Limited equipment for L5 simulation
  - <u>Pros</u>: Better Power Budget, Better Code/Carrier accuracy, New Concept for Space Test
- **L5/E5a waveform**
  - Need to have dual constellation capability (GPS + Galileo)
  - Need to have Signal Acquisition in Warm Start Mode



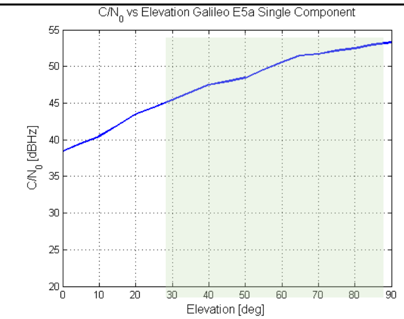
Galileo E1 Doppler



Galileo E1 Doppler Rate

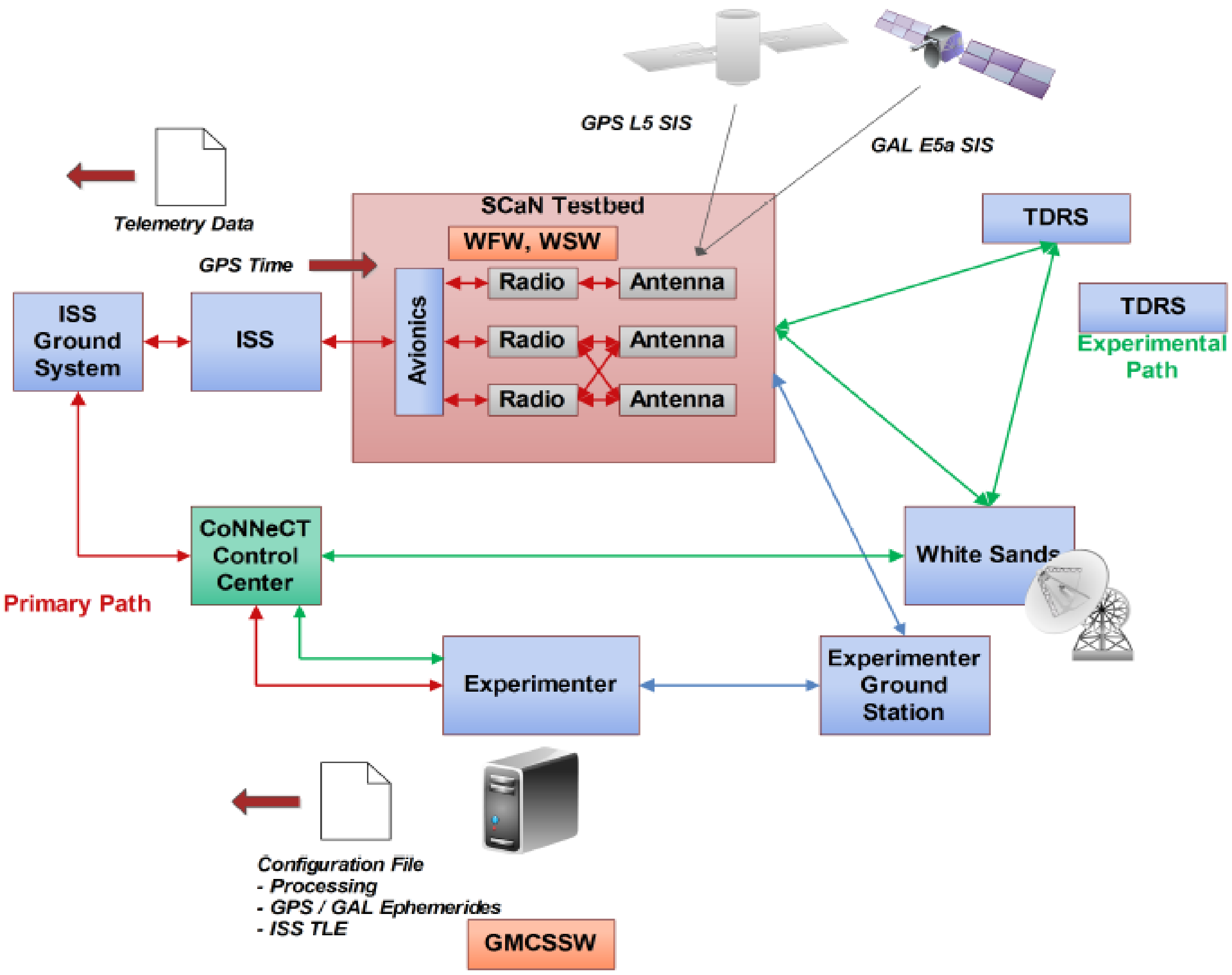


Galileo E1 CN0



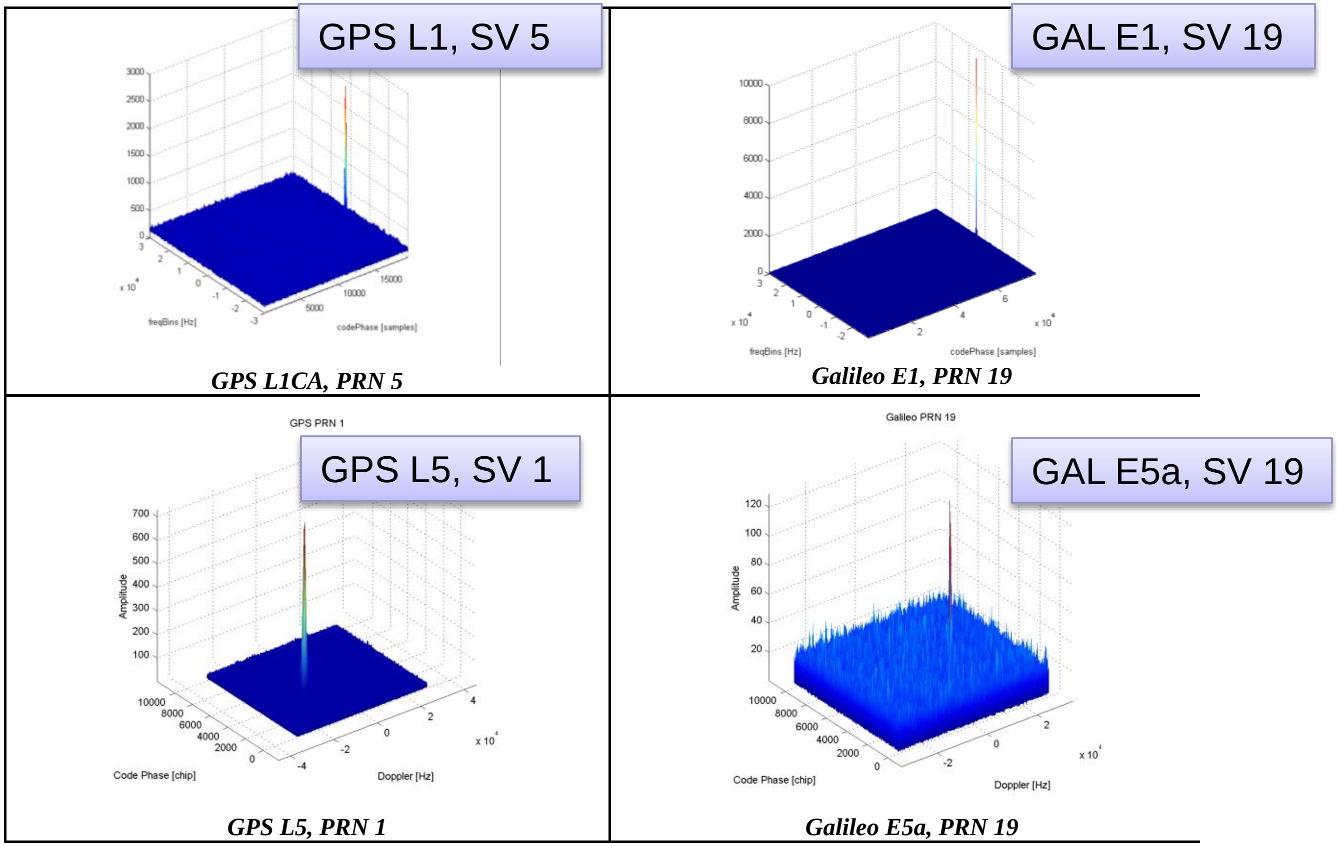
Galileo E5a CN0

Experiment Baseline



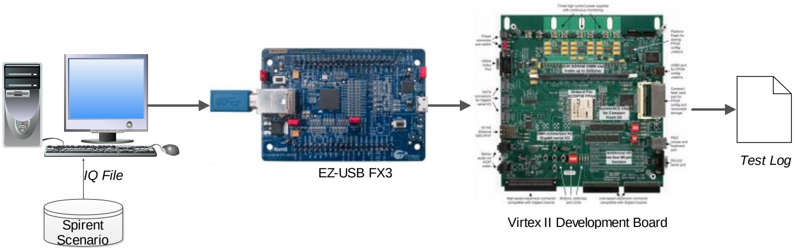
Acquisition of Signals collected on the ISS

- First Acquisition tests using IQ samples collected in the SCaN TestBed, (2013 Capture)



Approach to Verification and Validation

- Non availability in Europe of the JPL SDR Platform is one of the major challenges of the GARISS project
- Not possible to test the “closed loop” and the interactions between the SW and the FW.
- **Unit Level Testing:** will be executed for the two component of the Waveform (Software and Firmware). The Testing will be executed using selected boards representative of the JPL SDR architecture.
- **Development and Testing Tools**
  - **(FW) Virtex II Pro Development Board** including a Xilinx XC2VP30 FPGA where the Waveform Firmware is loaded
  - **(SW) STRS** Development Framework
  - **ISS IQ Scenario File**: this is an IQ file containing signals generated by Spirent constellation simulator. The files will dump the RF output of the constellation simulator in a realistic ISS scenario.
  - **Semi Analytic Signal Generator**: this will be used to replace the FPGA in the generation of the correlation values.

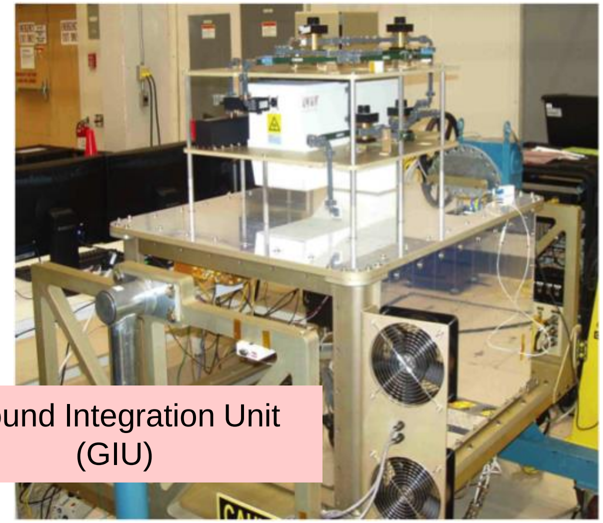


Approach to Verification and Validation

- **System Level Testing:** will be executed at NASA premises. The objective is the verification of the integrated waveform components. Two integrated systems are available: the Experiment Development System (EDS) and the Ground Integration Unit (GIU). EDS will be verified with LVDS simulators. The GIU with RF simulation.

- **Experimentation**: this activity consists in the in-orbit validation and experimentation of the Waveform (Second Half of 2017).

JPL radio EDS with RF subsystem



Ground Integration Unit (GIU)

Conclusions and Way Forward

- GARISS project has the objective to develop and experiment a multi-constellation Galileo and GPS receiver for the ISS
- The GARISS Waveform design will exploit the STRS development framework
- Preliminary FW and SW Design has been presented to ESA and NASA
  - The experimentation will focus on L5/E5a (Very Innovative)
  - Warm Start acquisition mode will be implemented (aiding data from ground and timing from the ISS)
  - Signal Acquisition has been demonstrated using real samples
- Approach for integration and verification has been defined in two steps
- In Orbit experimentation is foreseen for the second half of 2017
- The SCaN testbed is currently a unique opportunity to experiment navigation SDR technologies in the space

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Thank you for the attention!

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