Integrated Test Bench for rapid GNC design, verification and validation

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INTRODUCTION

The design process of a Guidance Navigation and Control subsystem (GNC) of a spacecraft must keep an eye on the later verification of its requirements. In order to meet the tight schedule that is usual in recent missions, the GNC and its Special Checkout Equipment (SCOE) are built in parallel. The GNC-SCOE will be used for the design of the GNC, and also during its Assembly Integration and Verification (AIV) campaign.

The GNC is integrated in a test bench with the GNC-SCOE for verification and validation. The GNC-SCOE is based on the simulation models of all GNC sensors and actuators, and has also a model for the Dynamic and Kinematic Environment (DKE). A modular architecture allows the replacement of simulation models by real hardware models.

The GNC-SCOE can also be integrated with the rest of the Electrical Ground Support Equipment (EGSE) for system verification and for Telemetry/Telecommand (TM/TC) handling.

GENERAL CONCEPT

The GNC-SCOE allows GNC subsystem verification in a staggered approach. It is a low cost solution and it provides high flexibility in the design process as the verification and validation can happen in parallel.

The GNC-SCOE supports development and verification processes for the GNC subsystem before launch. It is used further on for verification of satellite processes which are based on specific attitude states and which need execution of attitude scenarios.

The three GNC development and verification stages are depicted in Fig. 1, together with the GNC-SCOE incremental configurations.

In the first stage, The GNC has only available the GNC Software with the algorithms coded in it. For this purpose, Matlab/Simulink is used. In this stage, it must provide a software interface that matches the GNC Software interface, and simulate the DKE, sensors and actuators in a manner, that the GNC Software functionality can be verified.

In a second stage, the GNC Software is integrated with the Basic Software and the rest of the Application Software functions to compose the On Board Software (OBSW). The GNC Software is thus executed in a representative target processor, so it runs in real time, and uses representative interfaces. The test bench will reproduce as much as possible space flying conditions, allowing high fidelity emulation for the GNC. The GNC-SCOE is used in two modes:

- Open loop to test individually all the different interfaces with sensors and actuators.
- Closed loop to verify the performances of the GNC. In this stage a connection with the other test environments is considered, therefore an interface with the TM/TC Front End Electronics (FEE) is implemented.

In a third stage, the GNC will have also representative hardware. In this configuration, the test bench uses some of the real sensors and/or actuators, for high representativeness. Depending on the hardware availability, Functional Models (FUMO) can also be used. Two different new tasks have place in this scenario:

- The GNC-SCOE provides stimuli to the hardware sensors.
- The GNC-SCOE monitors the real hardware actuators actuation, measuring it in a manner that can be used as an input to the DKE running in the GNC-SCOE.

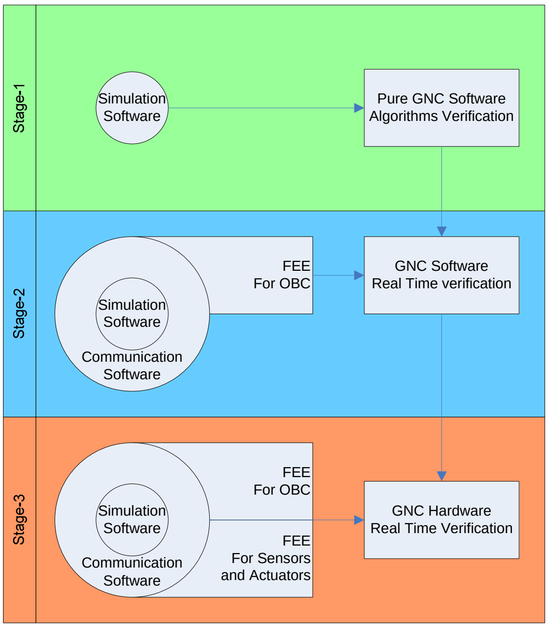

Figure 1. GNC Development Stages

The logic order of the GNC verification phases matches the order of these GNC-SCOE development stages. The tests developed for the first stage can be inherited for the second and third stage, by making simple modifications. The verification of specification requirements is mainly performed in the second stage, whilst the final validation of the models can be completed by using hardware in the loop as in the third stage.

The list of functionalities to be verified with the GNC-SCOE includes:
- Sensor measurements (stimulation and acquisition).
- Actuator behavior (simulation and acquisition).
- DKE.
- GNC algorithm / control command.
- GNC Interface.
- Failure Detection Isolation and Recovery (FDIR).
- Communication.
- Ground system.

GNC SCOE ARCHITECTURE

The GNC-SCOE contains all the hardware and software elements needed to test a GNC. It is used to virtually close the satellite attitude and orbit control loop on earth. The GNC-SCOE needs hardware for the different stages to do the activities listed below:
- Measuring satellite actuator activities. Needed in stage 3 for Hardware in the Loop (HIL) actuators.
- Reading satellite actuator commands. Performed in stage 2, and also in stage 3 for simulated actuators.
- Calculating the corresponding effects to the satellite attitude and position status. This is the common part for all the stages (1, 2 and 3).
- Emulating outputs from sensors. Performed in stage 2, and also in stage 3 for the simulated sensors.
- Stimulating the satellite interfaces according to the calculated attitude and position status. This is needed in stage 3 for HIL sensors.

Apart of connecting all relevant GNC interfaces, the GNC-SCOE is integrated with the external CORE-EGSE elements, and therefore it provides a local control through a specific Man-Machine Interface (MMI), as well as the Ethernet access to be incorporated in the EGSE Local Area Network (LAN).

GNC SCOE SOFTWARE ELEMENTS

The main software elements run in different computers, but the core software element is composed of the Simulation and the Communication Software. They both run on the SCOE Controller, which is located in the SCOE-Rack.

The Simulation Software provides the simulation models listed in Tab. 1.

Table 1. GNC and DKE simulation models

Type	Model
GNC Sensors	Gyro (1 axis)
	Gyro (3 axes)
	Magnetometers (1 axis)
	Sun Sensor (Pyramid)
	Sun Sensor (Single axis)
	GPS (1 antenna)
	GPS (Multi antenna)
	Star tracker
	Rendezvous Camera
	Capture Tool Sensor
GNC Actuators	Reaction Wheels
	Magnetic Torque
	Thrusters
	Single Gimballed CMG's
	Thruster Orient Mechanism
	Solar Arrays Drive Motor
	Electric Prop (Hall Effect)
	Capture Tool Boom
Orbit Dynamics	Numerical Orbit Propagator
	Numerical Orbit Propagator 2
	Numerical Orbit Propagator (Alt)
	Keplerian Orbit propagator (Alt)
	Keplerian Orbit propagator with acceleration (Alt)
	Keplerian Orbit propagator (only from clock)
	Keplerian Orbit propagator (with acc only from clock)
Attitude Dynamics	Numerical Attitude Propagation
	Orbital Angular Motion
	Nadir Pointing Attitude
	Kinematic Attitude Propagation
	Local Orbital Frame
	Numerical Attitude Propagation (Alt)
	Numerical Orbit Propagation (Alt)

Type	Model
External Disturbances	Lunisolar
	Gravity Gradient torque
	Solar pressure Forces
	Solar pressure torques
	Magnetic torque
	Third body effect (all planets)
Internal Disturbances	Flexible Appendages Influence
	Internal Energy Dissipation due to Liquid Fuel Motion
Ephemerid	Eclipse status
	GPS Ephemerid
	Moon position
	Sun position
	Earth position
	Mercury position
	Neptune position
	Jupiter position
	Saturn position
	Mars position
	Uranus position
	Venus position
	Pluto position
Earth Environment	EGF (Central Term)
	EGF (Spherical harmonics)
	EGF (central+j2)
	EGF (alt)
	Atmosphere density (0-1000km)
	Atmosphere density (0-100km)
	Geomagnetic Field (Spherical harmonics)
	Geomagnetic Field (Spherical harmonics / Variable)
	Geomagnetic Field (Spherical harmonics / Alt)
	Geomagnetic Field (Spherical harmonics / Variable / alt)
	External Magnetic Field T89c
	External Magnetic Field T96

Apart of these elements, the SCOS-EGSE and the Test Language run in the SCOS Host, and finally the MMI Software runs in the MMI Host. SCOS, Test Language and MMI Software are used to control the test execution and monitor the test results. They are described in the following subsections.

Simulation Software

It is the engine of the GNC-SCOE, which provides all the needed test capabilities, to allow verification at unit level and subsystem level. Simulator software is structured in models. Thus, it contains sensor models, actuator models, and DKE models. Models can implement a complete simulation for a certain unit, or just the needed signals to support the unit hardware in the loop. It is able to run in real time, and provides visualization and logging of all relevant data.

Communication Software

It provides the communication layer for the Simulation Software, establishing communications both with the hardware connected to the GNC under test, and with the external control and display systems (MMI and CORE-EGSE).

- Serves as EGSE router, for remote control.
- Handles the communications with the MMI for local control.
- Includes all related software interface for analogue and digital signals, and handles MIL-1553 bus traffic, as well as the synchronization tasks.

SCOS-EGSE Software

This is the software based on SCOS-2000, used for operations by ESA, here used for AIV campaigns. It manages all missions by means of a mission database.

Test Language

It is normally an extension of a common script language, e.g. TOPE is an extension for tcl/tk.

SCOE MMI Software

This software is the interface for the user. It provides the following functionalities:

- Local control of the SCOE.
- Simulation control.
- Log control.
- Error injection control.

GNC-SCOE HARDWARE ELEMENTS

The main hardware element is the SCOE Rack, which will be placed close to the GNC under test. The SCOS Host and the MMI Host provide the needed interfaces for the test. The SCOE Harness is used to connect the GNC hardware, and the SCOE LAN is used to interconnect all hosts. These elements are depicted in Fig. 2 and described in further subsections.

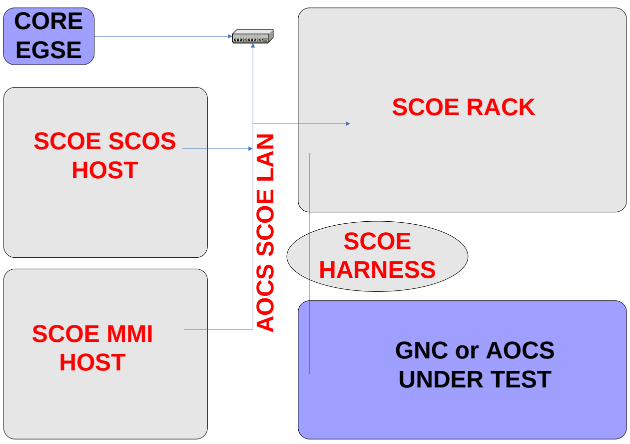

Figure 2. GNC-SCOE Hardware

SCOE Rack

It is a rack that contains all the software and hardware for the real time simulation. It is a 19” rack, with several sub racks. SCOE-Rack architecture is shown in Fig. 3. The following hardware is installed in the rack:

- SCOE Controller, which is an embedded computer, running a real time operating system. In this host will be running both the Simulator software and the Communication Software.
- SCOE-FEE, using COTS boards for all the required on board equipment interfaces, providing and acquiring the interface analogue and digital signals, as well as the communication buses.
- SCOE power module. It can provide power to all the SCOE units, but it is not designed to test power requirements.
- Break Out Box, where signals enter from the Input/Output (I/O) boards, grouped by signal type, and are distributed to their corresponding unit connectors, according to the satellite electrical Interface Control Document (ICD).

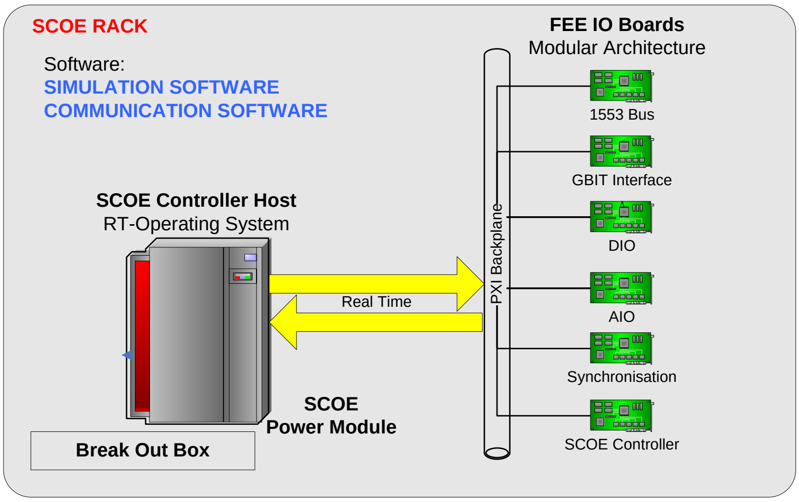

Figure 3. GNC-SCOE Rack

SCOE MMI Host

It is a computer that hosts the SCOE MMI software to provide command and monitor tools for the GNC-SCOE. As shown in Fig. 4, it hosts the SCOE MMI, a customized environment with the communication with all the I/O boards implemented. Normally the SCOE MMI Host is a single computer where all the software is installed, but it can also be enlarged with additional computers or archiving media in case of additional needs for data archiving or for more developers working in parallel.

SCOE SCOS Host

It is a computer that hosts the SCOS-EGSE software. It will host the Test Language where the AIV engineers will develop the test scripts. Sample SCOS-EGSE displays are shown in Fig. 4.

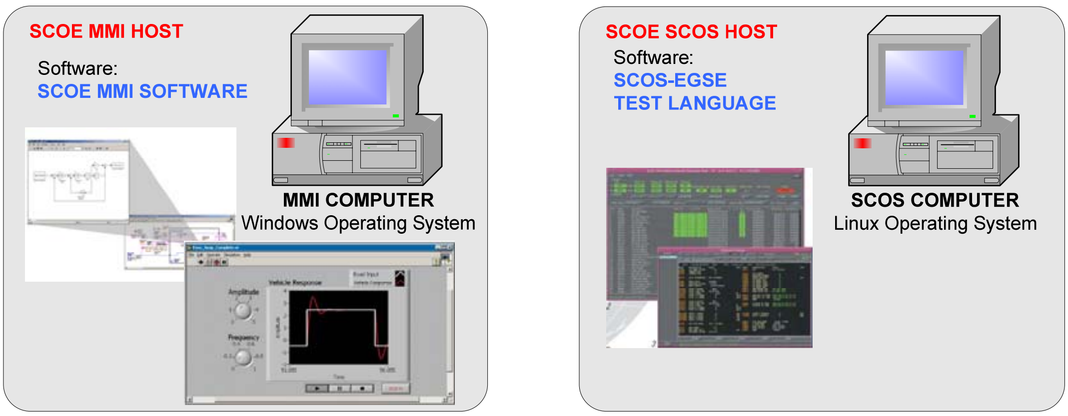

Figure 4. GNC-SCOE MMI Host and SCOS Host

SCOE Harness

The SCOE Harness will have the required length to reach the spacecraft connectors, providing all required signals to the On Board Computer, and also to the units, in either configuration, simulated or Hardware In the Loop (HIL). It can also provide test points, where additional equipment could be attached to monitor signals without affecting their values. It will be ready to support HIL and simulation configurations.

SCOE Local Area Network

The GNC-SCOE LAN connects all relevant GNC-SCOE hosts. The connection between SCOE Controller and SCOE MMI Host uses a Gigabit Ethernet, to allow high traffic demands. The SCOE LAN must provide enough capabilities so the SCOE MMI can display and archive simulation data during run time. The usage of an independent LAN isolates the GNC-SCOE from external LAN traffic and makes possible a specific access control policy.

SIMULATION SOFTWARE DEVELOPMENT PROCEDURE

To help the development of the Simulation Software used in the GNC-SCOE, a Software Development Environment is used. It is based on a set of common commercial software tools like compilers, converters, graphic languages, download tools, etc. Several different programming and developing common languages are supported, like Simulink and C. The simulator modules are merged into a single Simulation Software, and integrated together with the Communication Software to get finally a single executable file, that is executed in real time on the SCOE Controller.

This Simulation Software provides a very well defined interface to the Communication Software allowing the initialization of simulation parameters and modification of simulation variables during run-time.

MAIN GNC-SCOE FEATURES

Among others, the GNC-SCOE provides the following features.

Spacecraft Grounding Compatibility

The GNC-SCOE follows a grounding approach compatible with the spacecraft grounding philosophy. To avoid undesired wrong measurements, or safety problems, it is established with the following goals:
- Provide a safety path for faults currents.
- Prevent shock hazard.
- Provide a discharge path to prevent static charge accumulation.
- Provide an equipotential signal reference point.
- Avoid ground loops.

To achieve this, it uses the different ground points available in the test room:
- Safety Ground: It is referenced to the normal power outlets in the building and is used for safety.
- Facility Ground (or clean earth): It is available in clean rooms dedicated to space projects, and is used for signal reference purposes in noise-sensitive electronic systems.

The GNC-SCOE provides also different ground points as output to the GNC hardware:
- GNC-SCOE EGSE Ground: this is the secondary ground of the GNC-SCOE, which is used after an isolation transformer and is accessible on an external ground stud. It shall be used to connect additional EGSE equipment (oscilloscopes, etc).
- Secondary Power Ground (SPG): The secondary power of the GNC units is referenced to the spacecraft structure, which will be connected to the facility ground during the test.

Spacecraft Interface Protections

The GNC-SCOE is interfacing the GNC sensors, actuators, and On Board Computer (OBC). Special care must be taken to avoid any damage to the flight units, but also to protect the GNC-SCOE interfaces.

The GNC units are electrically stimulated and no physical stimulation is foreseen in the GNC-SCOE.

A fail-safe situation will be guaranteed in case of failure with the following approach:
- First line protection located in the GNC-SCOE for hardware (galvanic isolation, clamping, spike suppression and current limiting) and for software (checking of commanded output and value inside valid range).
- Second level protection located in power interfaces.

According to the type of signal, different interface modules and protection measures are considered:
- MIL-1553 bus is transformer-coupled.
- Voltage to Current Converter Output.
- Analogue Voltage Output.
- Analogue Voltage Input.
- Bi-Level Output.
- Bi-Level Open Collector Output.
- Bi-Level Input.
- Rs-422 Receiver and Transmitter.

Synchronization to Spacecraft

The GNC-SCOE includes a synchronization board with a high accuracy clock to synchronize the FEE using different timing standards, like IEEE-1588, or IRIG-B.

The Spacecraft OBC clock is designated as master clock. It will generate a synchronization signal to control all the measurement devices in the system. The GNC-SCOE measurement instruments will use this synchronization signal and can generate also synchronous output signals.

The GNC-SCOE can also be running with a free running clock, overriding the reference clock on the SCOE Controller. The accuracy is thus improved.

The SCOE Controller has its own clock, and eventually some other FEE modules have also their own clocks. The fact of using several clocks might lead to a clock drift even when the clocks were initially synchronized. The master/slave configuration is used in the GNC-SCOE to fix this problem. Clock skew and jitter are also taken into account in the GNC-SCOE design.

Error Injection to the Simulation Software and Calibration of the Front End Electronics

The error injection feature allows the test conductor to modify the outputs of any simulator model before they go to the FEE devices, and provides the ability to decide the time, the duration and the value to be set.

The calibration of the FEE can also be managed using a linear correction on a particular I/O signal. A Calibration Table is read at initialization time, and the required offset and gains are applied during the whole test. The Calibration Table can be modified according to GNC-SCOE diagnostics results.

Data Logging and Archiving

The GNC-SCOE has flexible data-logging and archiving capabilities. The SCOE Controller has a robust hard disk to allow for continuous operation. A periodic process dumps data to an external disk, which is subject to data safety measurements like redundancy and backups. The SCOS host is also used for the archiving of the SCOS data.

Self Test

The GNC-SCOE has Built-in-Test (BIT) capabilities. The operator can execute the self test prior to each GNC test execution. The test results of the BIT are automatically logged in a log-file, with the relevant test data (date, time, result…). BIT is structured in two levels:
- At first level, the FEE provides a self test capability up to a certain point inside the electronics (register level).
- At second level, FEE provides testing of I/O signals coming out of the FEE. It uses a dedicated circuitry, which can be automatically programmed to check GNC-SCOE before the GNC test, and provide the results of the self test.

SENER GNC-SCOE PREVIOUS EXPERIENCE

SENER GNC-SCOE has been developed in the ESA funded GATB project.

Two different products under test were used to validate the GATB:
- ASVIS VME Breadboard
- Planck Attitude Control Measurement Subsystem (ACMS) FUMO.

This current experience allows SENER to apply for many invitations to tender or requests for quotation, regarding both GNC-SCOE and also AOCS-SCOE.

ACKNOWLEDGMENTS

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