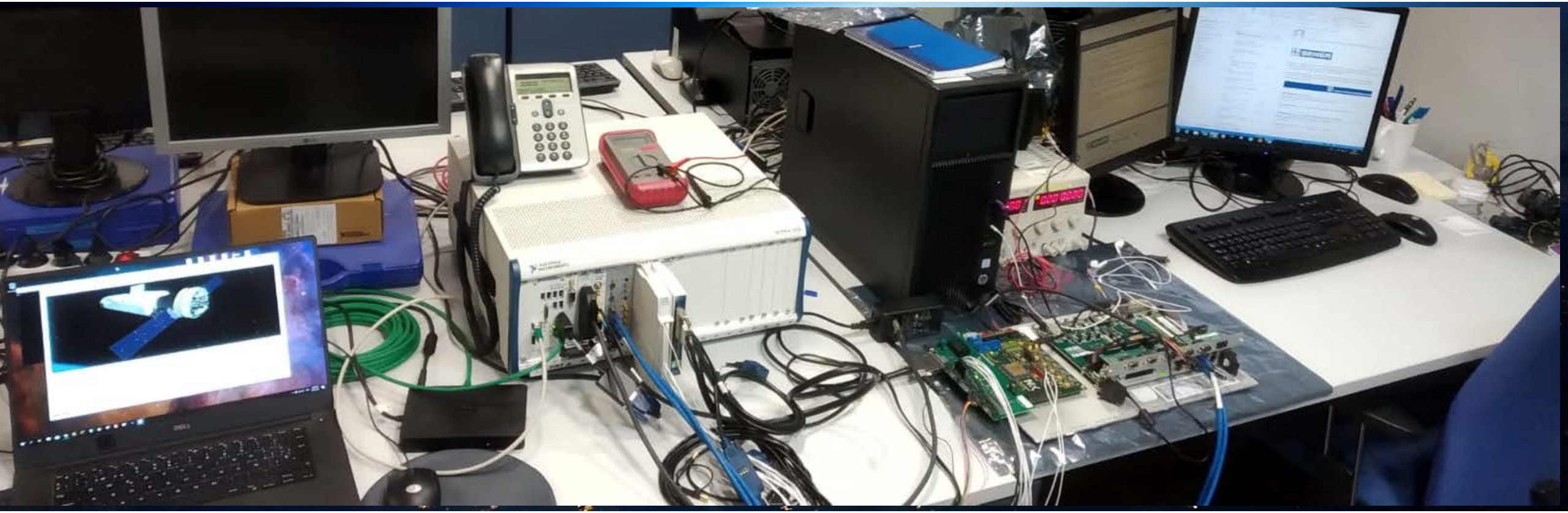
SENER
Aeroespacial

03/12/2019



CoRA SAGE: Smart AOCS&GNC Elements
Final Presentation

Juan Manuel del Cura

Index

CoRA SAGE

Attitude and Orbit Control Subsystem

Guidance Navigation and Control

Electrical Ground Support Equipment

CoRA SAGE Objectives

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Objectives

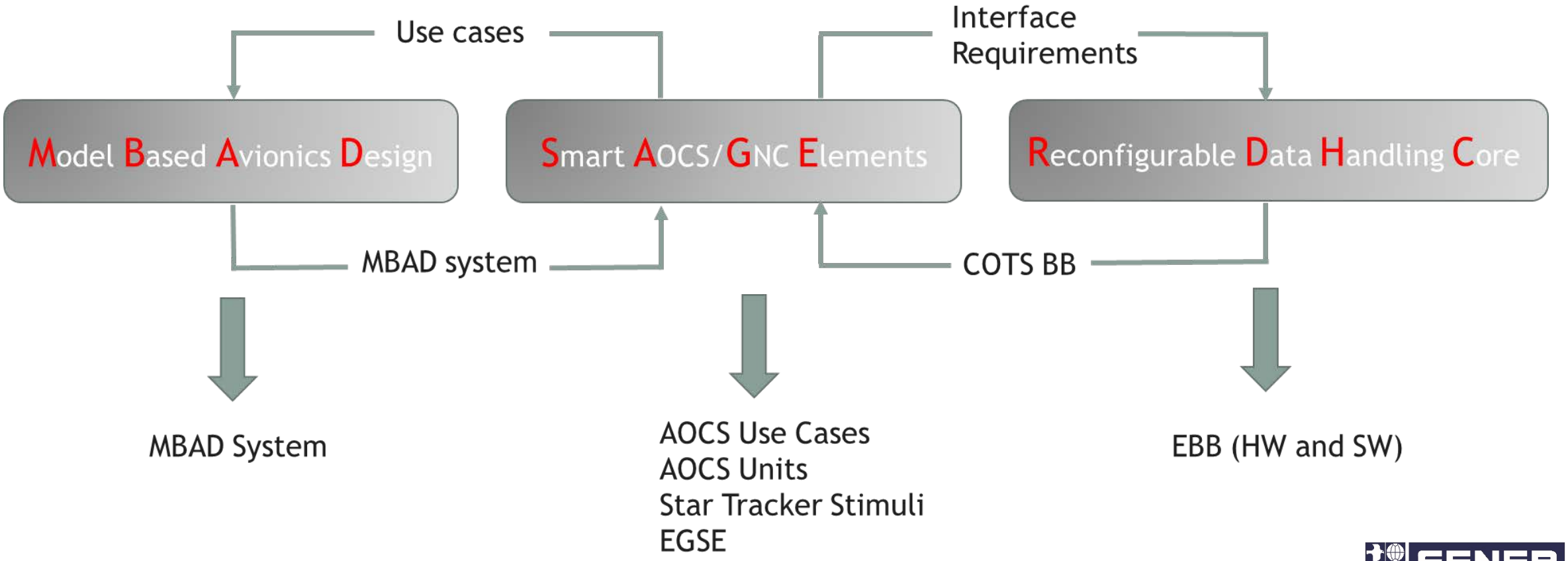
CoRA SAGE overview

CoRA Smart AOCS&GNC Elements (SAGE) is a **multidisciplinary** activity:

- AOCS & GNC functional chains
- EGSE
- Stimuli GSE

reliable sensors and actuators

compact & reconfigurable implementation



Objectives

Key Elements

Low Earth Orbit AOCS/GNC heritage

High pointing accuracy AOCS heritage

Atmospheric Entry GNC

Deep AOCS/GNC EGSE knowledge

Star tracker on a chip

Reusable Models and Functions

Multidisciplinary

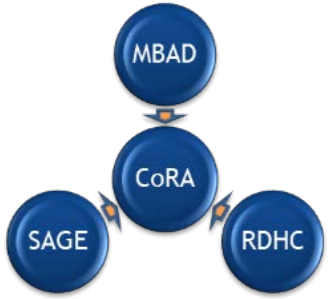
EGSE Reconfigurability

Experienced KP

Compliance

Risk Mitigation

Experienced consortium



Coordinated teams towards a common goal

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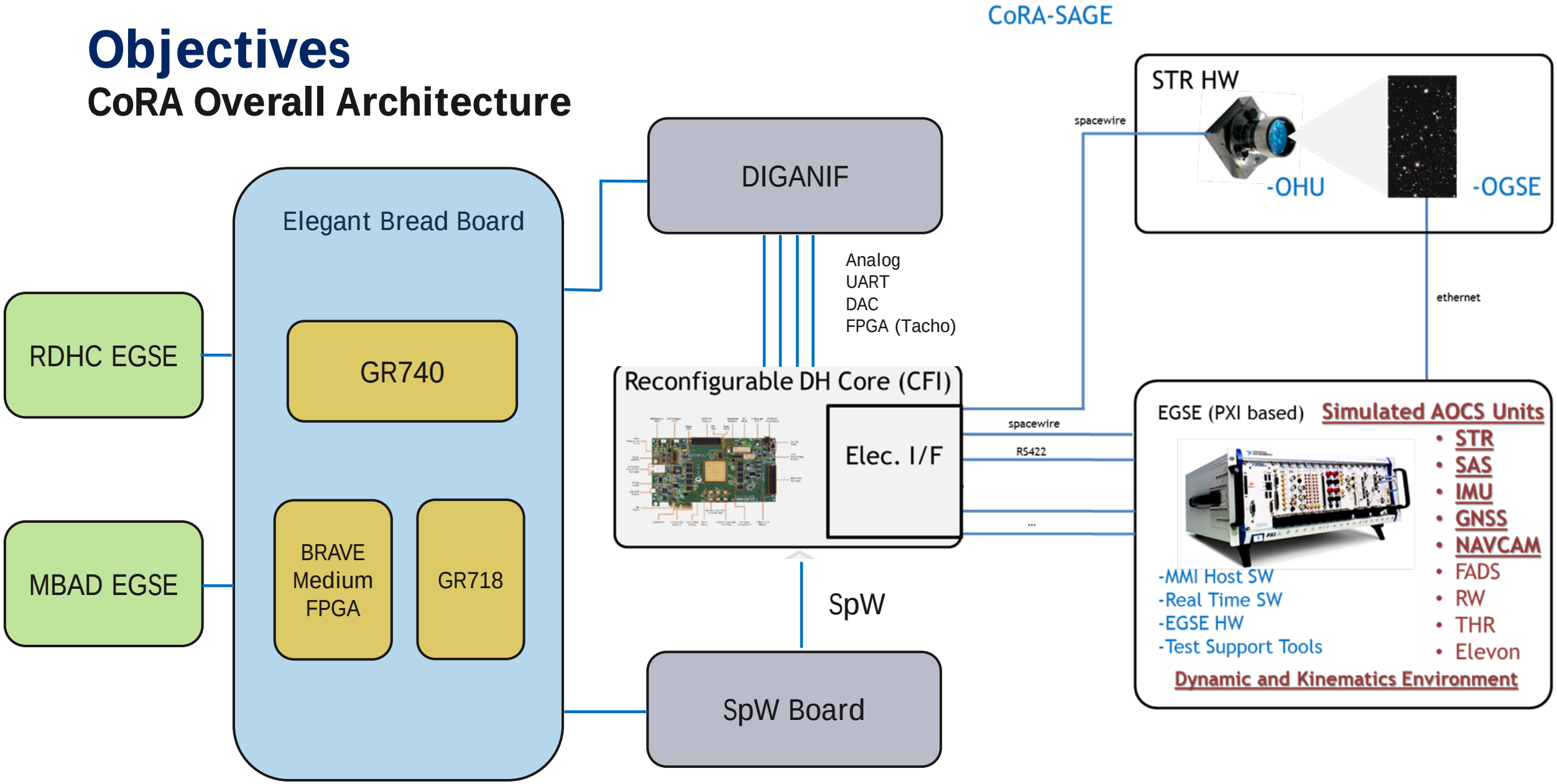
Objectives

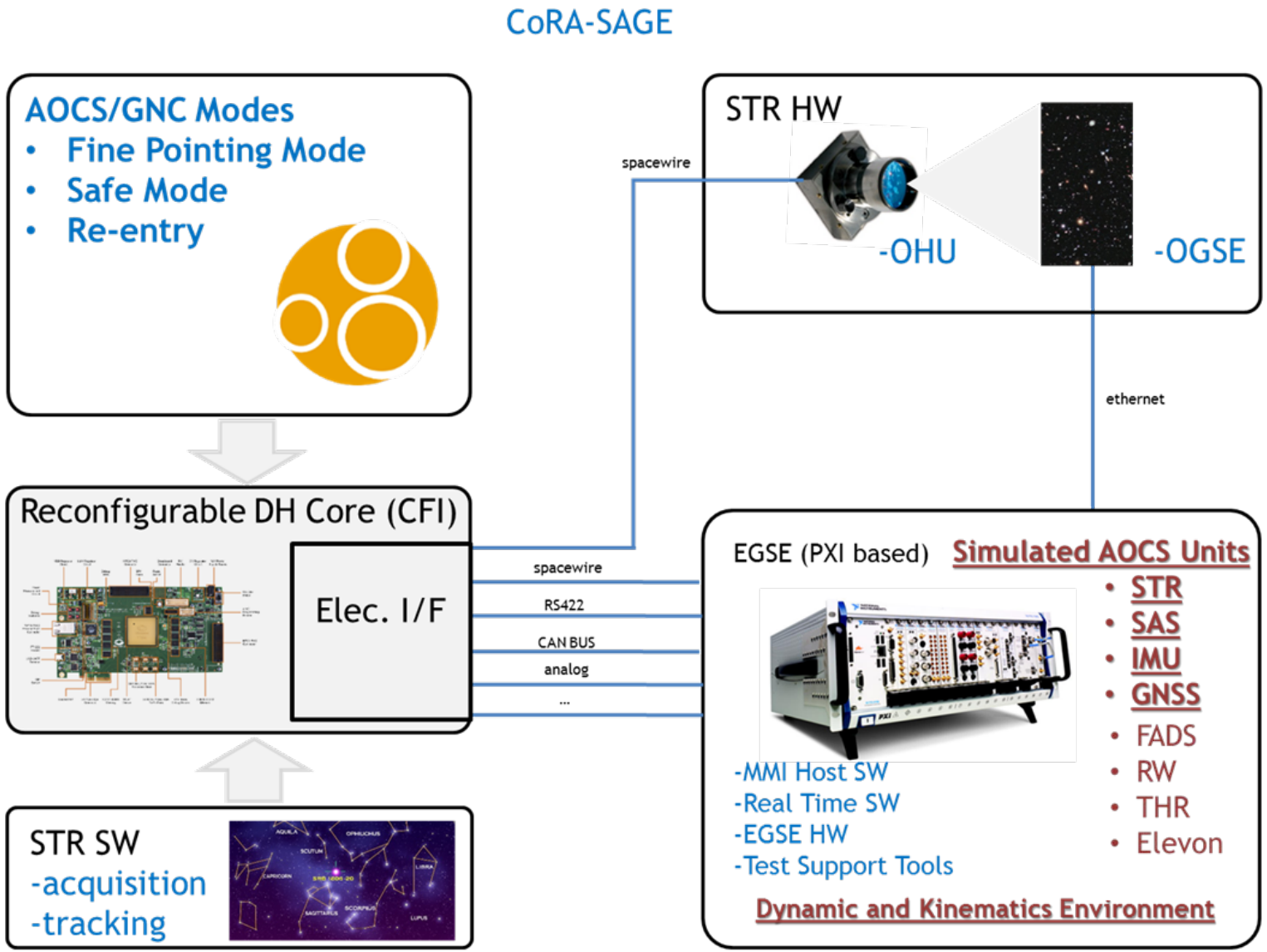
CoRA Overall Architecture



Objectives

SAGE product

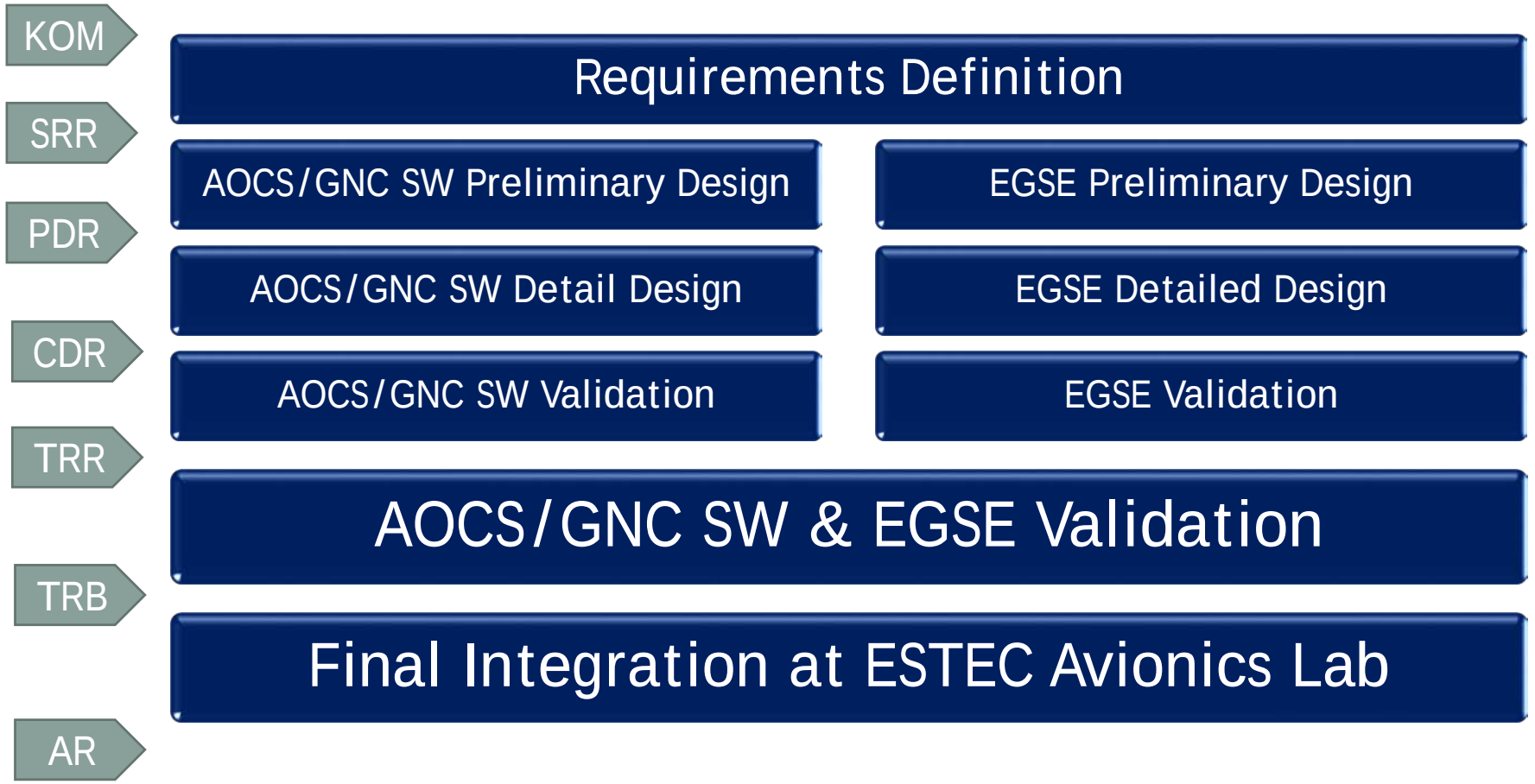
- AOCS/GNC Modes
- SAGE EGSE
- Star Tracker OH
- Star Tracker OGSE
- Star Tracker SW



Optical Head **Optical Ground Support Equipment**

Objectives

SAGE development flow



CoRA SAGE Consortium

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Consortium

SENER

Coordination
System Engineering
Integration

SENER

SAGE
EGSE

SENER

Data handling
HW & SW

SENER

AOCS/GNC
Modes
REM Navigation

Star tracker EM
& OGSE
Processing
Library

SODERN

Re-Entry Module
FDI and G&C

elecnor deimos

SENER

AOCS/GNC
Engineering,
Targeting of CoRA
Environment

CoRA SAGE AOCS/GNC Modes

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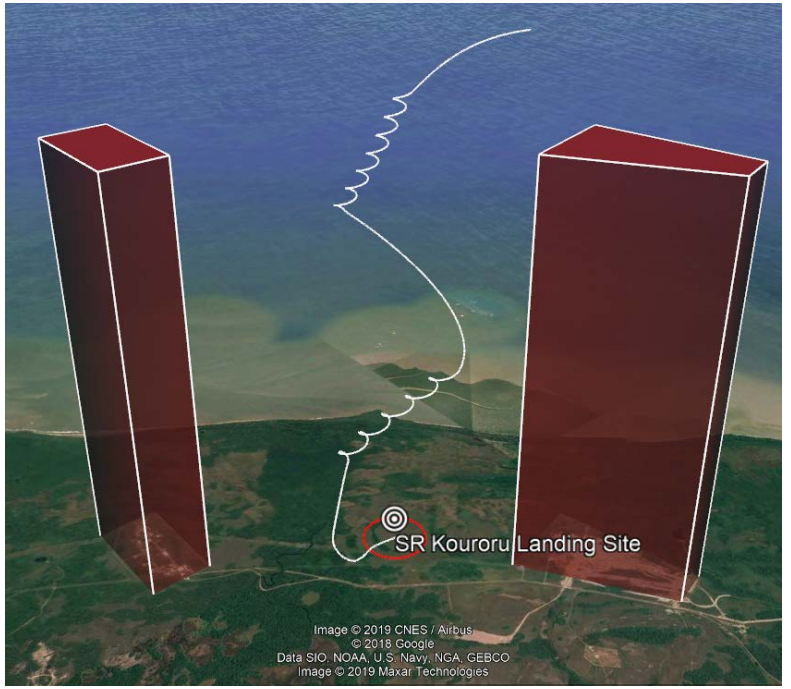
CoRA SAGE AOCS/GNC Modes

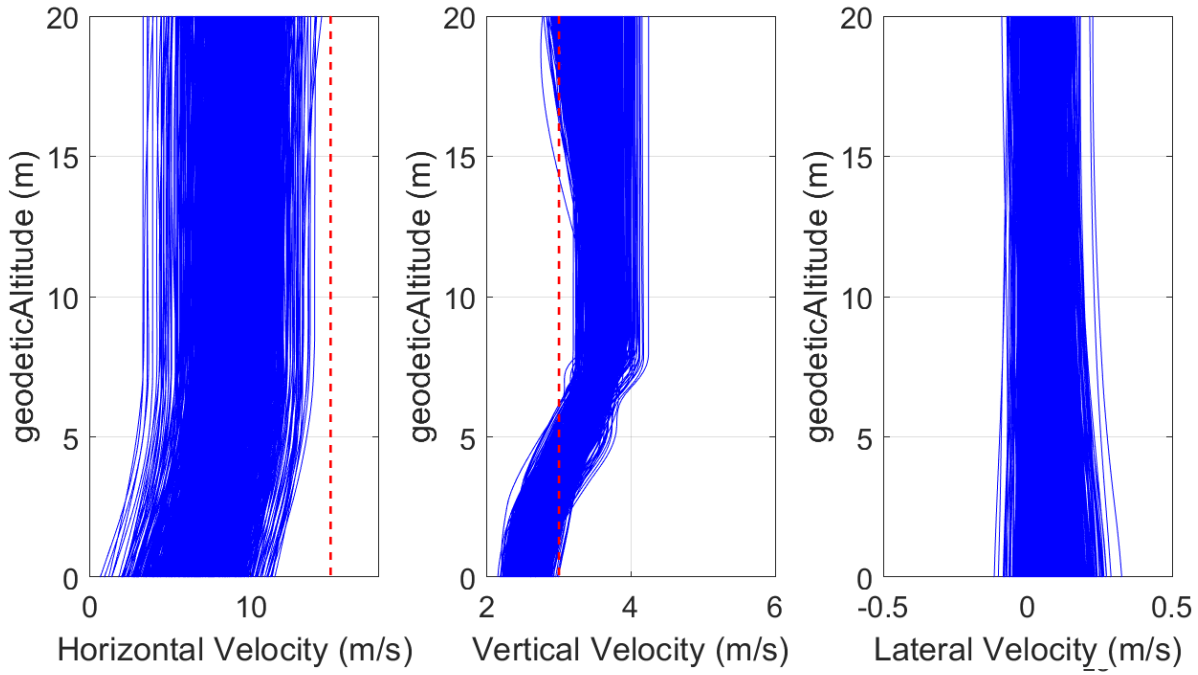
Baseline Mission

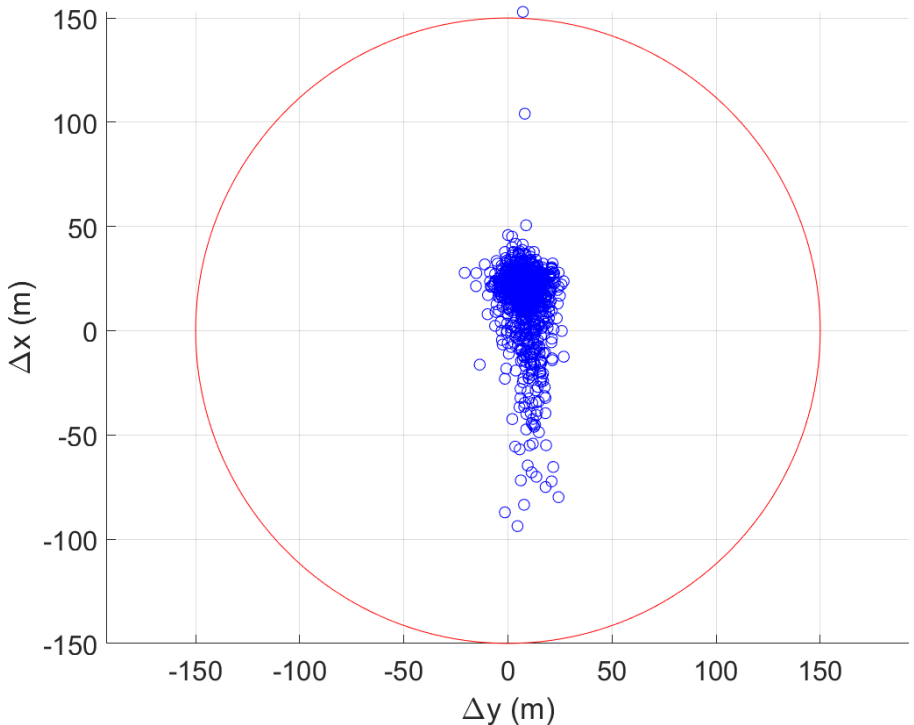
- CoRA SAGE baseline mission is **Space Rider**
- Space Rider is a reusable orbital vehicle designed to fly up to 6 times to carry out Earth Observation, Microgravity, Telescope and Rendez-Vous missions.
- Space Rider will be composed by an Orbital Service Module (OSM) and a Re-Entry Module (REM)
- Orbital mission and Re-entry serve as reference scenarios for CoRA-SAGE development
- SENER is responsible of the GNC subsystem, which has a strong heritage from IXV GNC
- CoRA SAGE baseline frozen on September 2017
- Space Rider mission has evolved since then -> Successful CDR on November 2019
- CoRA SAGE has not implement all changes in Space Rider configuration -> Not Space Rider anymore

CoRA SAGE AOCS/GNC Modes
Baseline Mission

- Some results from SR CDR.
- Space Rider reentry module landing requirements fully met even with large wind knowledge errors
- Landing accuracy requirement of **150m** fully met even with large wind knowledge errors







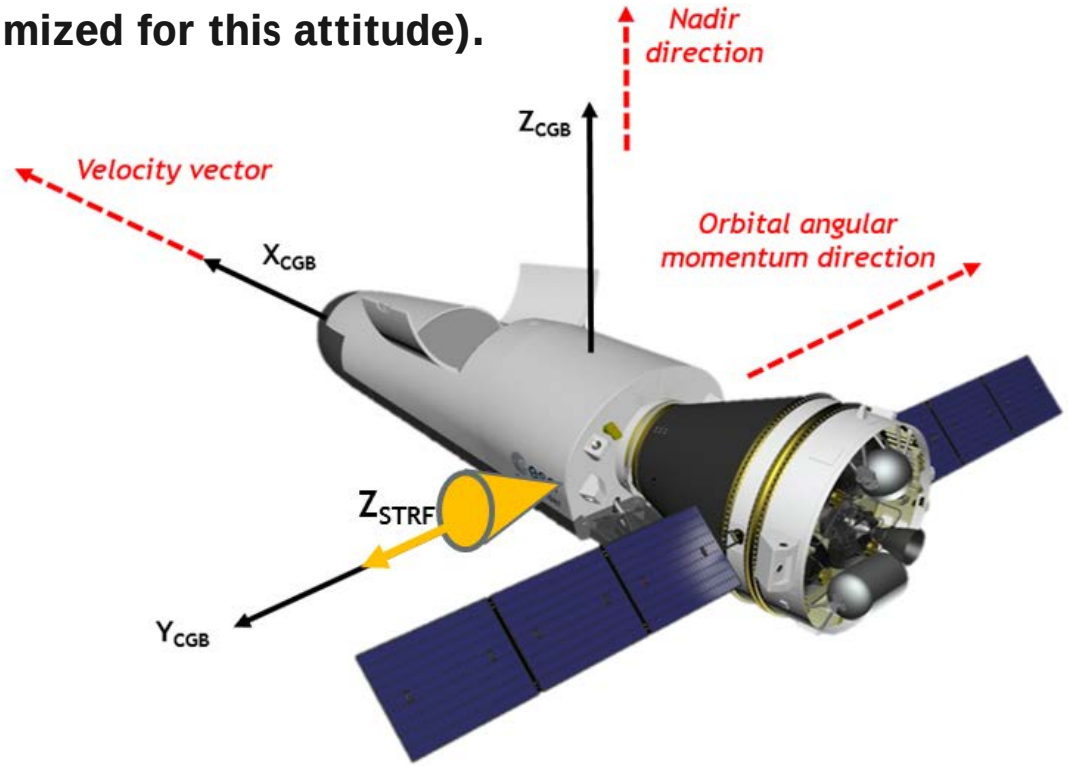
CoRA SAGE AOCS/GNC Modes

AOCS/GNC Mode selection

- In CoRA SAGE study, the following Space Rider-based AOCS/GNC modes are used as reference:
  - Safe Mode (SFM)
  - Fine Pointing Mode (FPM)
  - Re-Entry Mode (REM)
- This mode selection requires a large set of AOCS/GNC units, including:
  - Star Trackers (STR)
  - Global Navigation Satellite System (GNSS)
  - Inertial Measurement Unit (IMU)
  - Sun Acquisition Sensors (SAS)
  - Flush Air Data System (FADS)
  - Reaction Wheels (RW)
  - Reaction Control System (RCS)
  - Entry Elevons (ELEV)

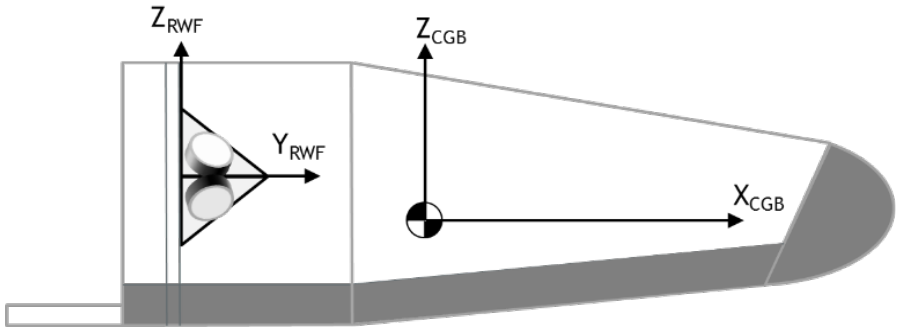
CoRA SAGE AOCS/GNC Modes
Fine Pointing Mode (1/3)

- **Objective:**
  - **Points the cargo bay to Nadir:**
  - **Earth Observation.**
  - **Micro-gravity experiments (aerodynamic drag is minimized for this attitude).**
- **Requirements:**
  - **Use primary sensors:**
    - **STR in Attitude Tracking Mode.**
    - **GPS in Attitude Tracking Mode.**
  - **Use RWs as actuators.**
  - **APE < 0.05º.**
  - **AMPE < 0.02º.**
- **Space Rider Configuration:**
  - **Solar panels perpendicular to X_CGB.**
  - **STR boresight axis parallel to+ Y_CGB.**
    Sun is out STR FoV with this lay-out.

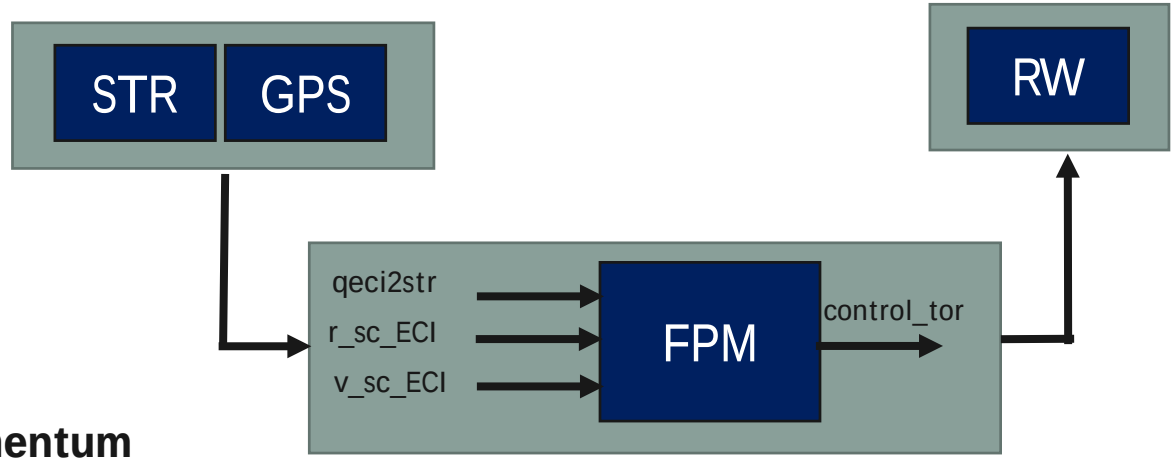


CoRA SAGE AOCS/GNC Modes

Fine Pointing Mode (2/3)

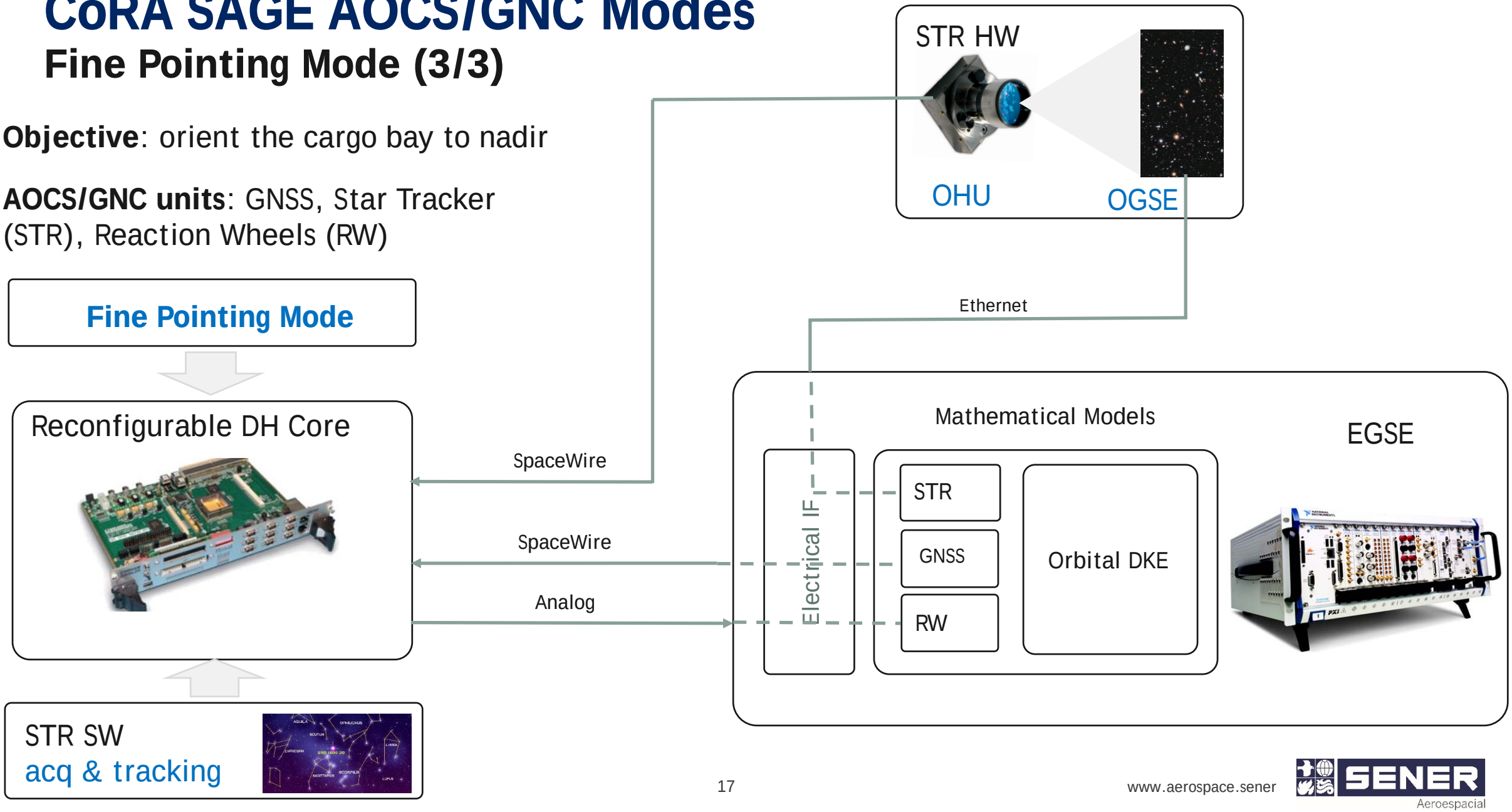


- AOCS units:
  - STR x1: AURIGA Simulink model provided by Sodern
  - GPS antenna x1
  - RWs : 4 wheels in pyramidal configuration.
  - Modelling: heritage of SENER validated models.
- Control objectives:
  - Cargo bay pointing to Nadir:
  - Z_CGB parallel to the Nadir direction
  - Minimize aerodynamic forces:
    - X_CGB parallel to the velocity vector
  - Keep the same attitude during the orbit:
    - Y_CGB parallel to the orbital angular momentum
    - Rotate with the orbital angular rate around -Y_CGB



CoRA SAGE AOCS/GNC Modes
Fine Pointing Mode (3/3)

- **Objective**: orient the cargo bay to nadir
- **AOCS/GNC units**: GNSS, Star Tracker (STR), Reaction Wheels (RW)



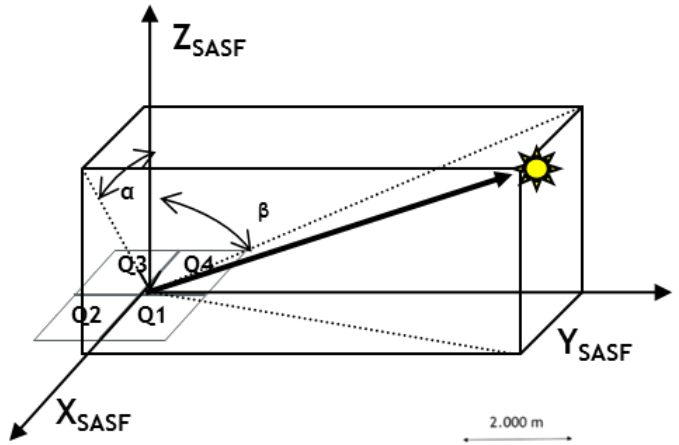
CoRA SAGE AOCS/GNC Modes

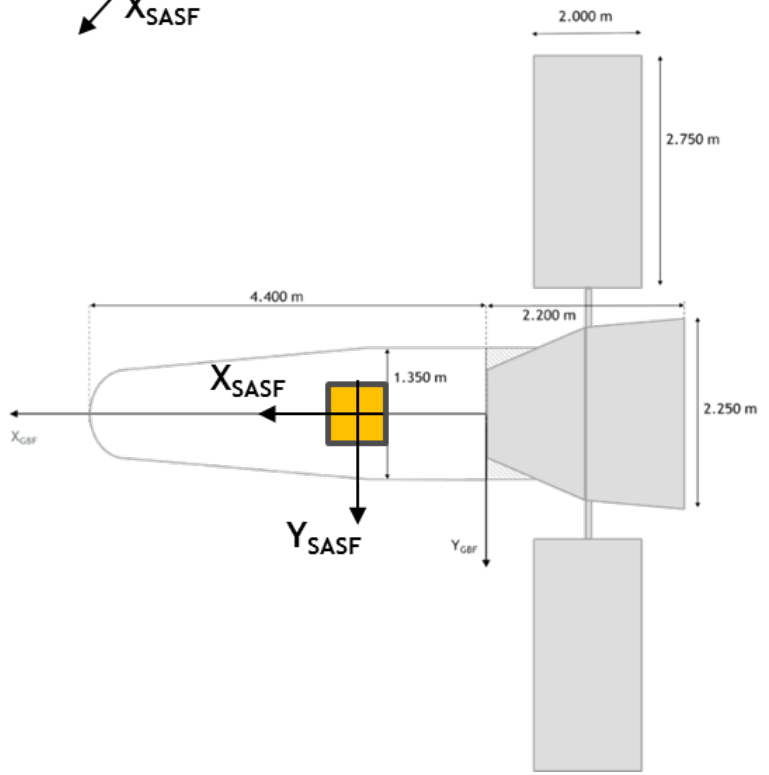
SaFe Mode (1/3)

- **Objective:**
  - **Point the sun with the solar arrays in a fixed position.**

- **Requirements:**
  - **Use redundant sensors: SAS and IMU.**
  - **Use RCS as actuator.**
  - **APE < 15º.**

- **Space Rider Configuration:**
  - **Properties frozen at SR status in 05/18**
  - **Solar panels perpendicular to Z_CGB.**
  - **SAS boresight axis is parallel to -Z_CGB.**





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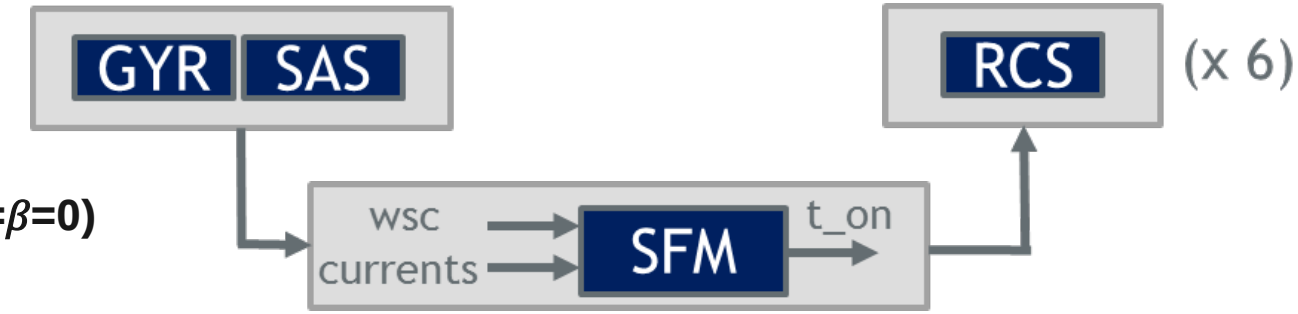
CoRA SAGE AOCS/GNC Modes

SaFe Mode (2/3)

- AOCS units:
  - SAS x1 (redundant units not included in the design)
  - IMU x1
  - RCS : 6 Thrusters of 220N
  - Modelling: heritage of SENER validated models.

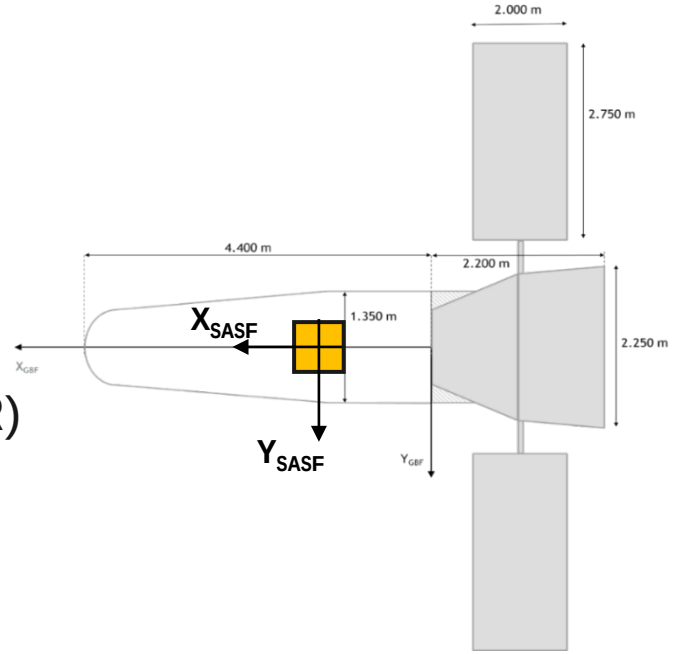


- Control Objectives:
  - Keep SAS and Solar arrays illuminated:
    - Z_CGB parallel to the Sun direction (α=β=0)
  - 3-Axis control:
    - Null ω^z
  - Align SAS and Solar panel to the Sun after eclipse period:
    - Use GYR measurements to integrate angular error when SAS is not illuminated

CoRA SAGE AOCS/GNC Modes

SaFe Mode (3/3)

- **Objective**: orient the solar arrays towards the Sun
- **AOCS/GNC units**: Sun Sensor (SAS), Inertial Measurement Unit, Thrusters (THR)



Safe Mode

Reconfigurable DH Core

SpaceWire

Analog

RS422

Electrical IF

Mathematical Models

Gyro

SAS

THR

Orbital DKE

EGSE

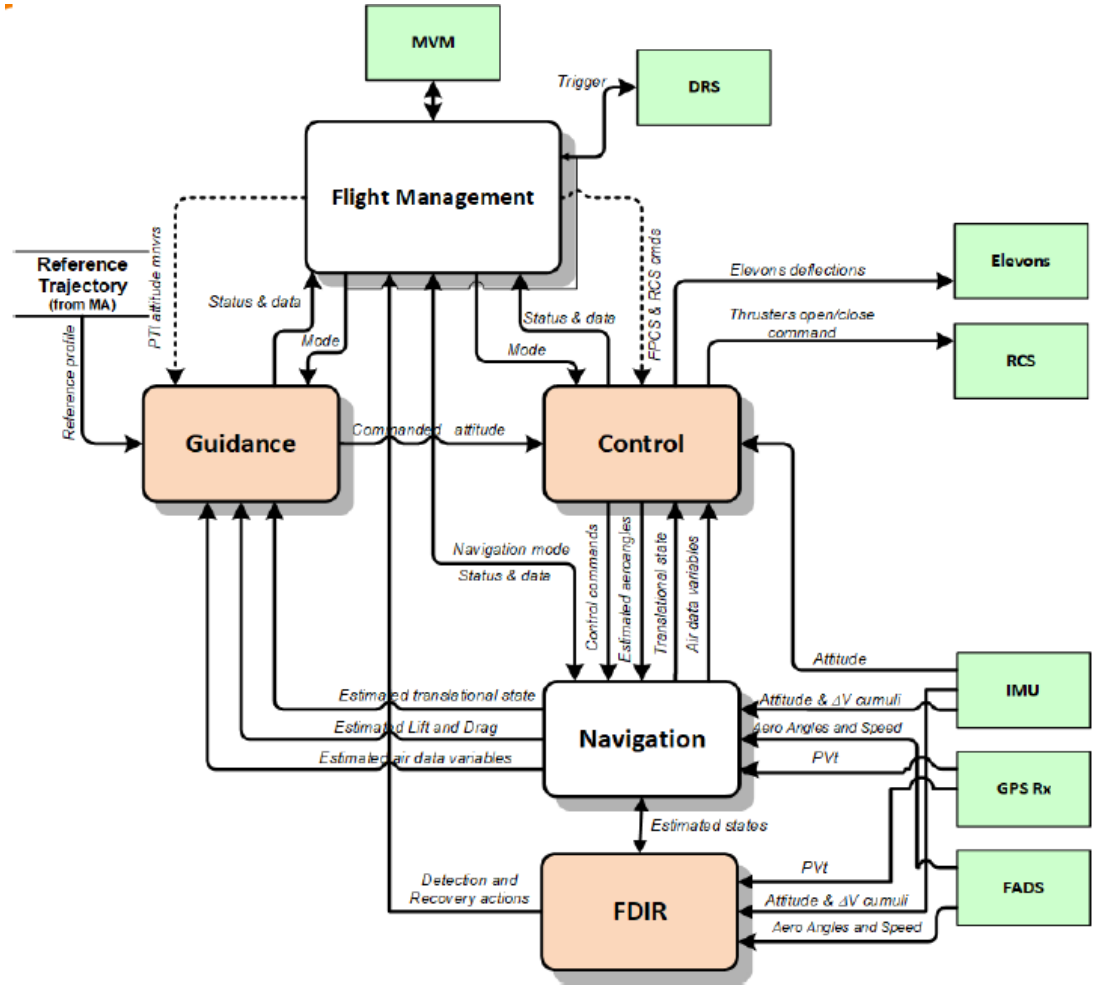
CoRA SAGE AOCS/GNC Modes

Re-Entry Mode (1/3)

- **Objective:**
  - **Implementation of a safe re-entry trajectory based on IXV upto parachute deployment. ensuring to fly within the entry corridor.**
  - **Implementation of a FDI function for handling failures in FADS sensor during re-entry and convey the information to Flight Management for reconfiguration**

- **Requirements:**
  - **Use redundant sensors: FADS, IMU and GNSS.**
  - **Use RCS and Elevons as actuators.**

- **Space Rider Configuration:**
  - **Properties frozen at SR status in 05/18**
  - **Velocity along +X_CGB.**

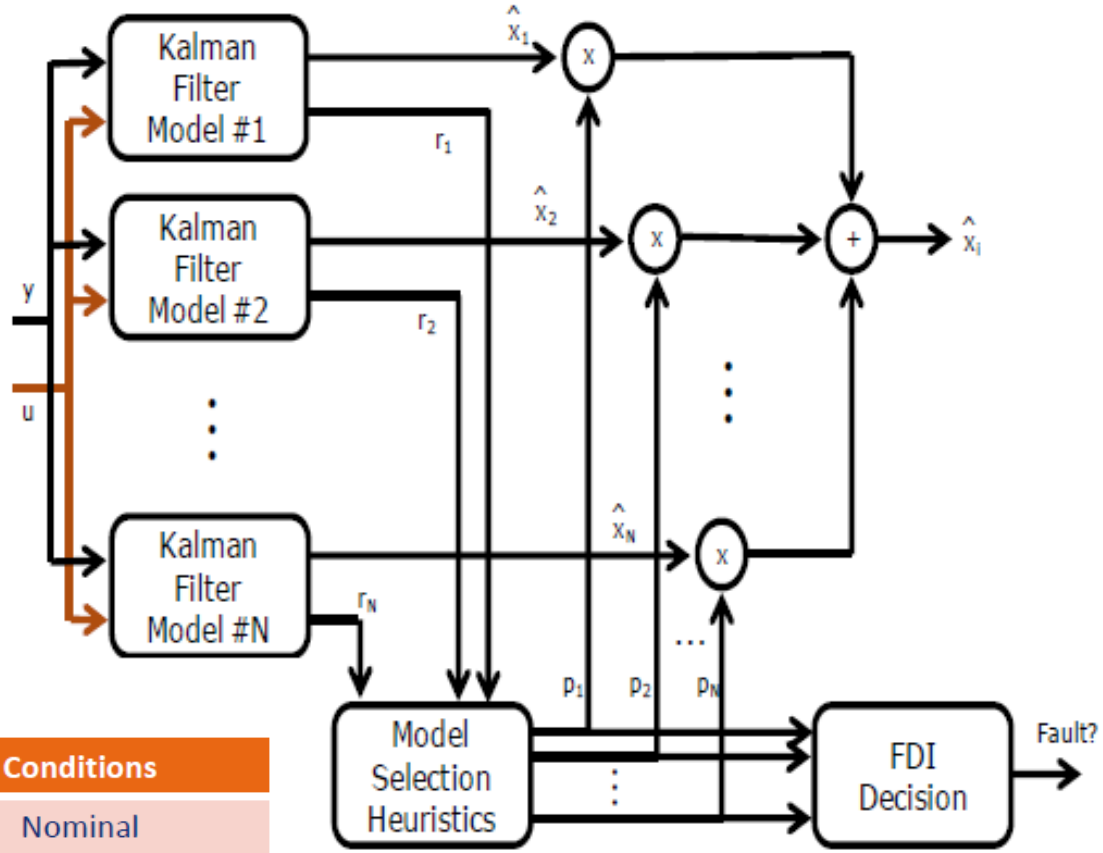


CoRA SAGE AOCS/GNC Modes

Re-Entry Mode (2/3)

- AOCS units:
  - FADS x1
  - IMU x1
  - GNSS antenna x1
  - RCS : 6 Thrusters of 220N
  - Elevons
  - Modelling: heritage of SENER IXV validated models.

- Control Objectives:
  - Keep the trajectory within the entry corridor
  - Detect and isolate FADS sensor failures
  - Provide inputs for reconfiguration



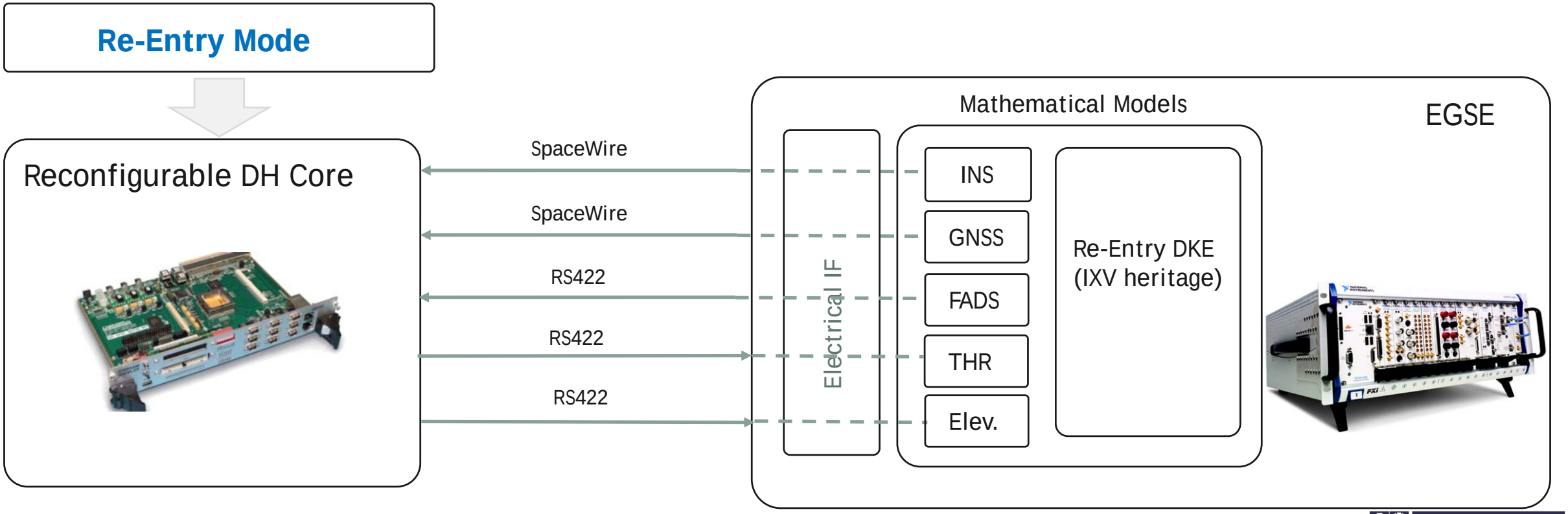
Model #	Conditions
1	Nominal
2	Failure in Aero-Angle
3	Failure in Mach
4	Failed FADS

CoRA SAGE AOCS/GNC Modes

Re-Entry Mode

- **Objective**: follow nominal trajectory
- **AOCS/GNC units**: GNSS, INS, FADS, THR, Elevons

- **Dynamics, Kinematics and Environment (DKE) Models**: mathematical models employed in IXV design, verification and validation



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CoRA SAGE AOCS/GNC Modes

Summary

Complexity

- Safe Mode (SFM)
- Fine Pointing Mode (FPM)
- Re-Entry Mode (REM)

Reconfiguration scenario

CoRA SAGE EGSE

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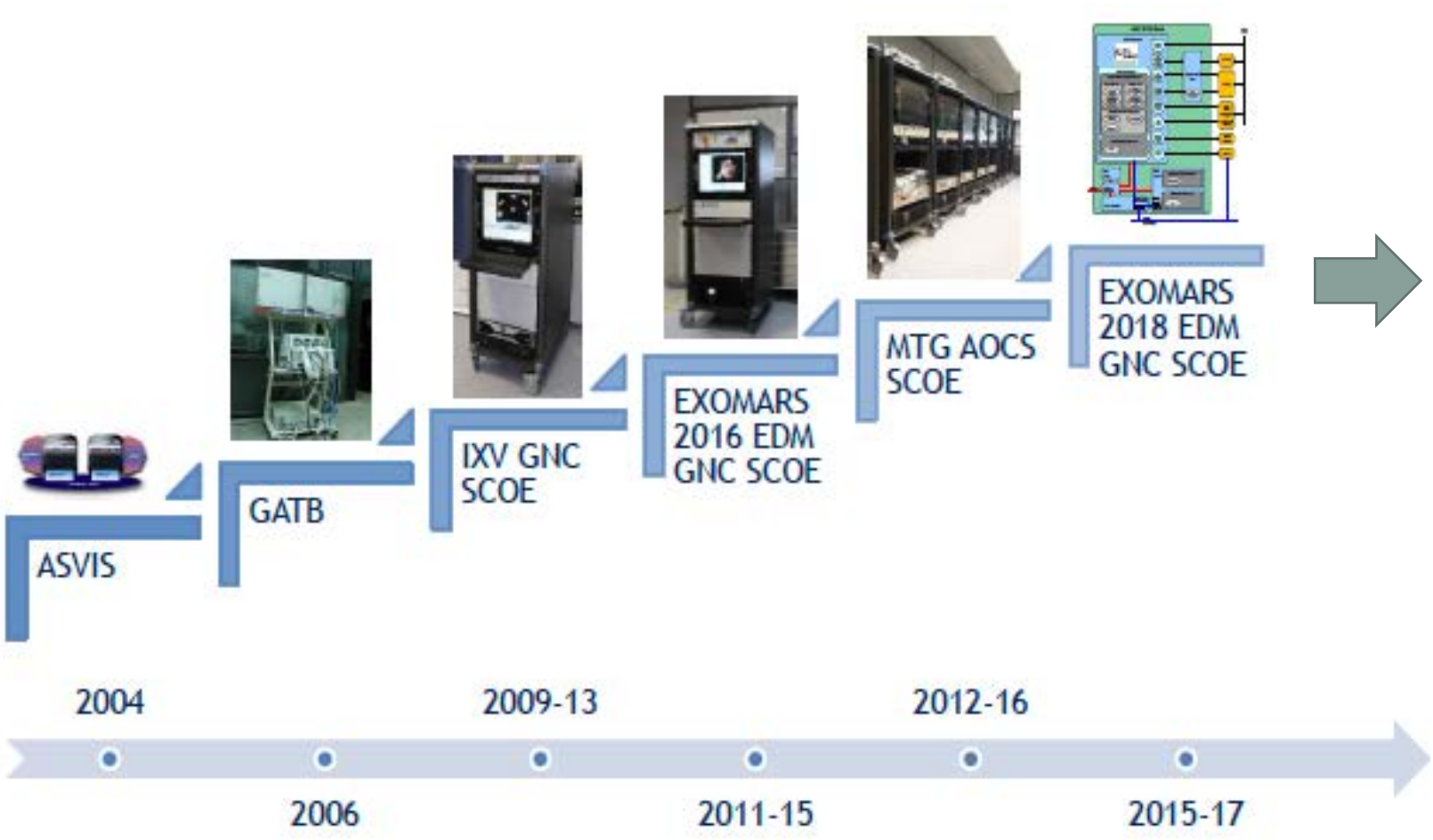
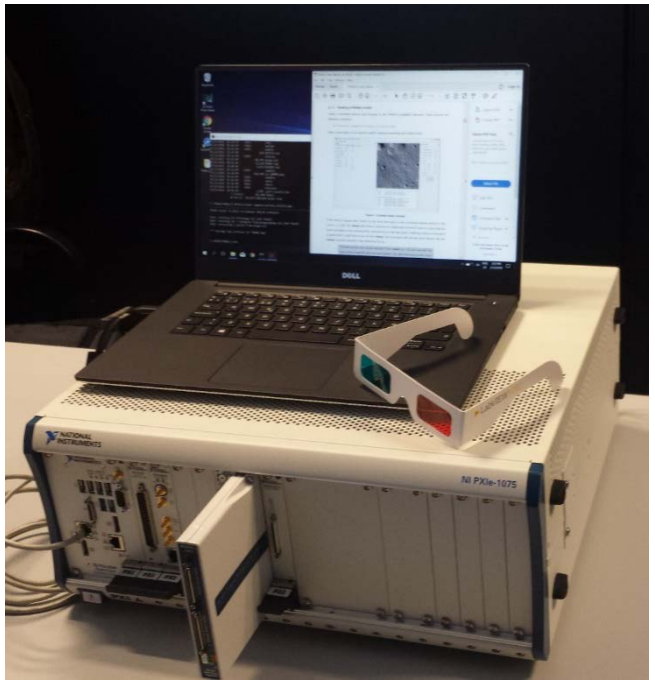
EGSE
Background





CoRA EGSE 2019

Special Check Out Equipment

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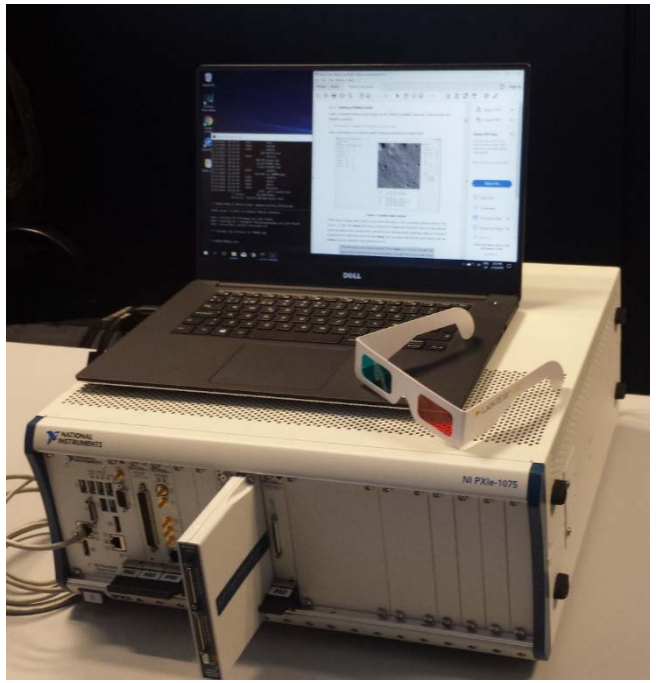
EGSE

Reusing HW & SW Elements

- **MMI**: Reused and modified from ExoMars and MTG
- **National Instruments PXI & Labview**: Used in previous SCOEs and EGSEs in Sener.
- **SAS Simulation**: simulating Solar cells with current output boards. Used in previous SCOEs
- **FPGA to simulate Tachometer**: Simulating Tachos/second from RW reusing sections of code from MTG RW's



LabVIEW 2017

exomars

CoRA EGSE 2019

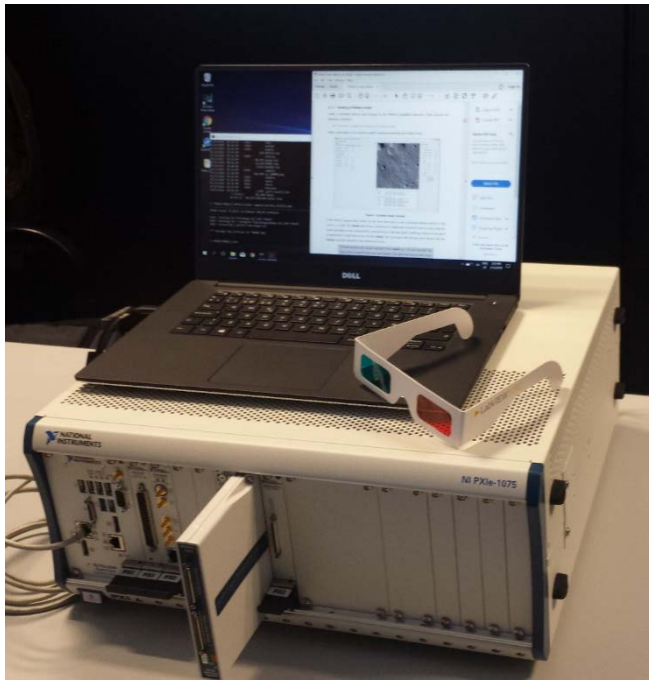
Man Machine Interface

EGSE

New additions in CORA SAGE

- **Spacewire**: used to simulate STR
- **Auriga STR OGSE**: simulating a map of stars depending on the quaternion provided by the DKE.
- **Synchronization Board**: used to provide a stable timing reference to the EGSE system.

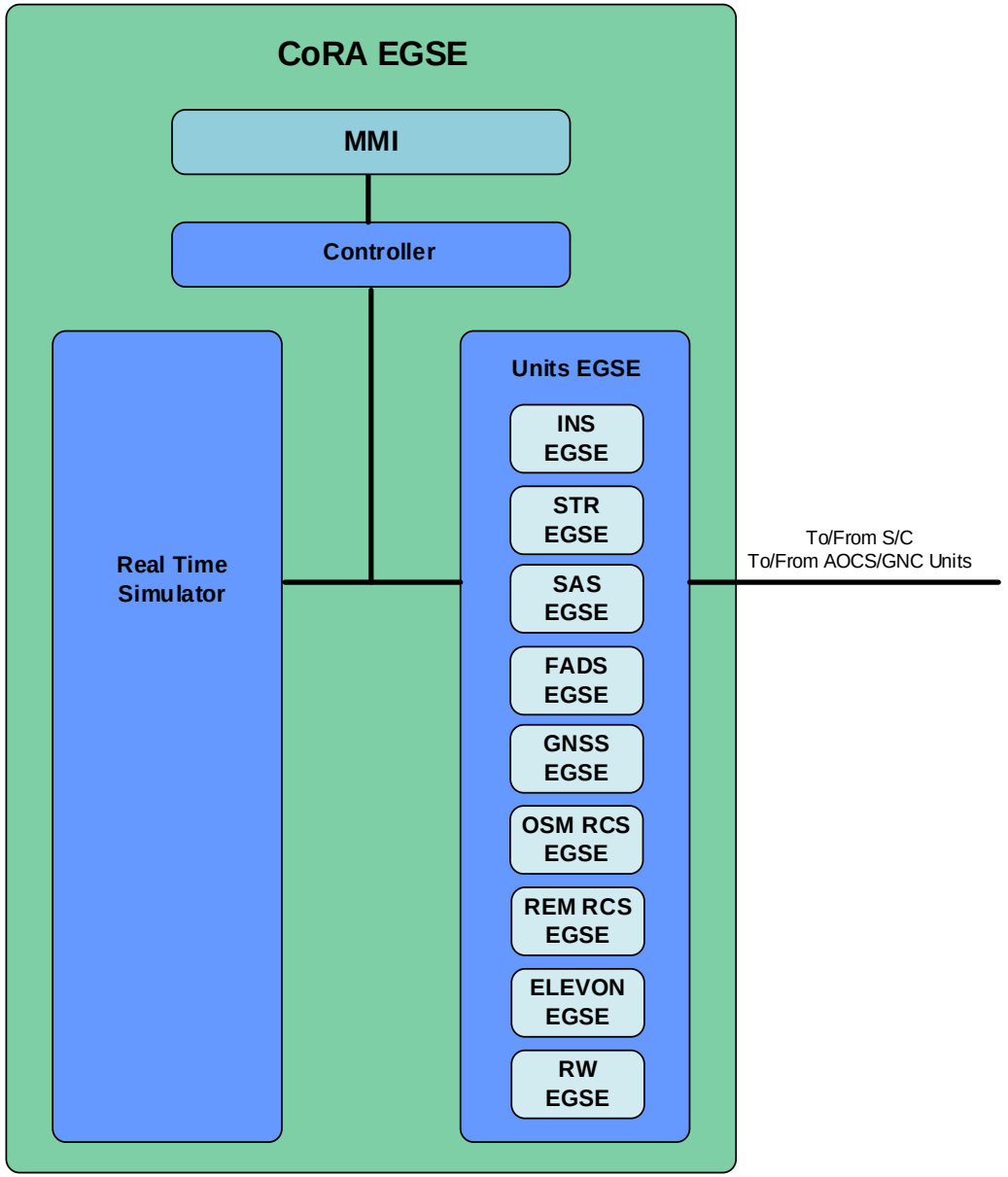
STAR-Dundee



CoRA EGSE 2019

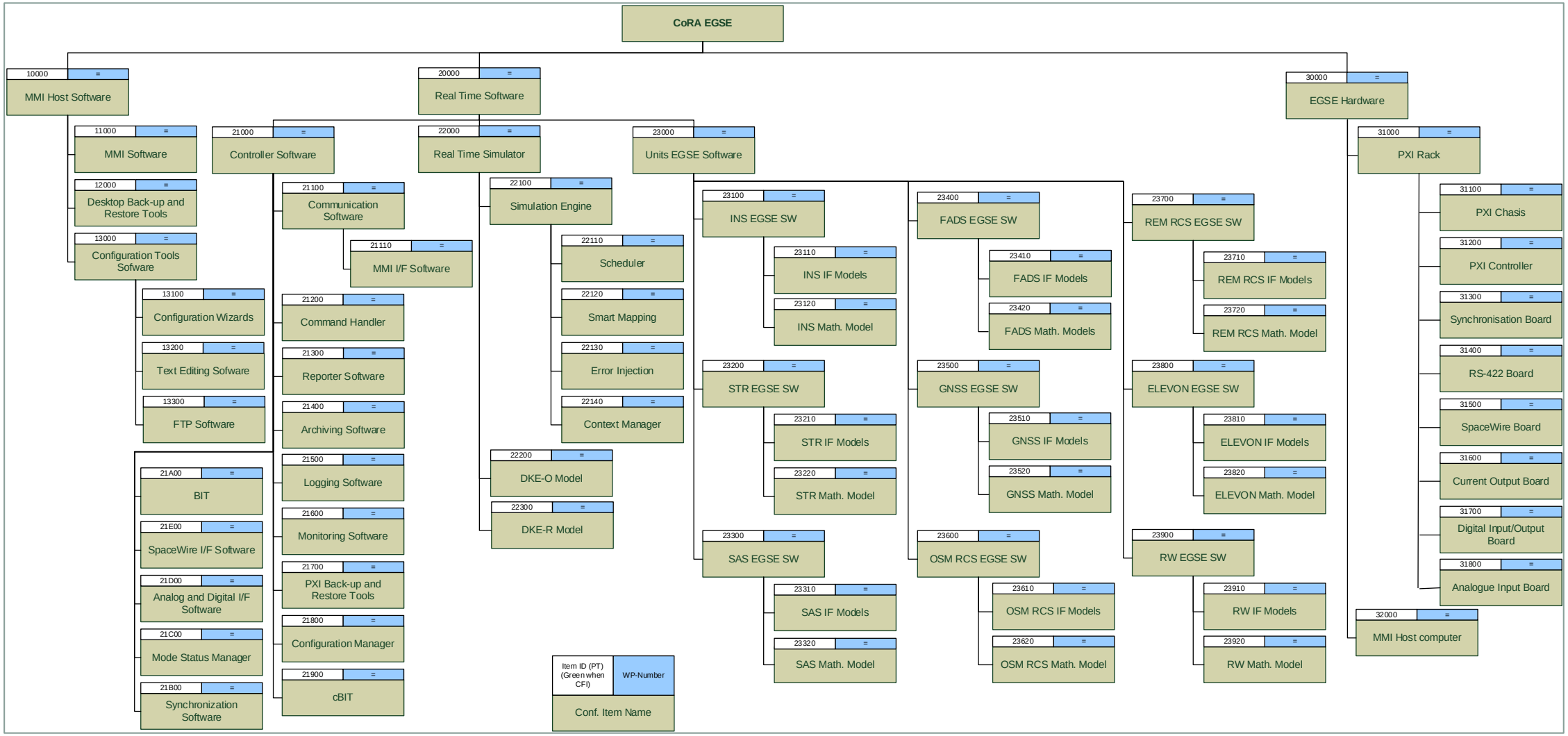
EGSE
Functional Diagram

- **MMI**: operate locally the CoRA-SAGE EGSE
- **Controller**: coordinates the operation of all components
- **Real Time Simulator**: implements the environment and spacecraft dynamics models
- **AOCS/GNC units**: front end interfaces to the equipment under test and the simulation and stimulation functions



EGSE

Product Tree



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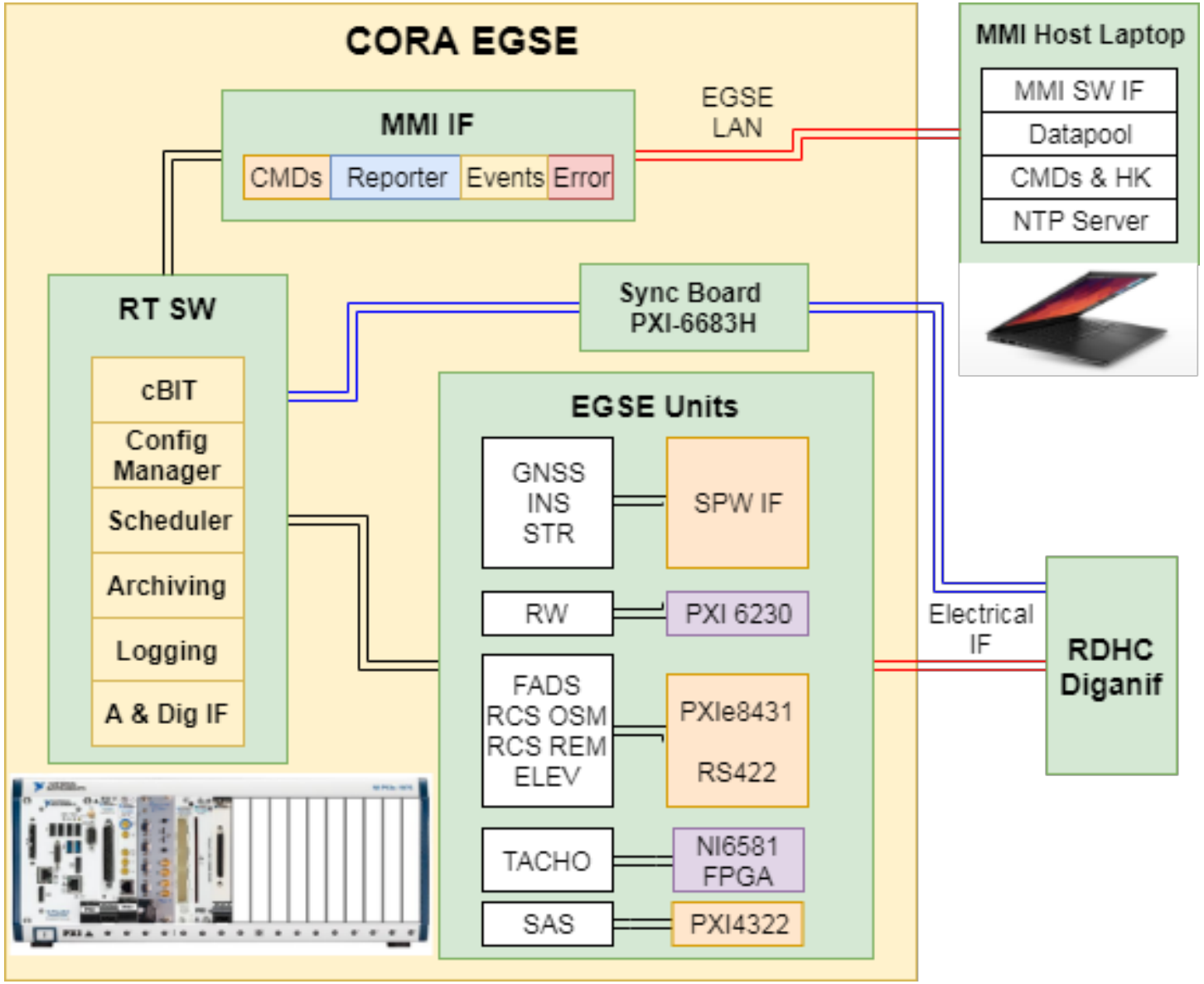
EGSE
Characteristics

- Real Time (RT) simulation:
  - Scheduler at 200 Hz
  - Math Models (AOCS units and DKE)
- Data-pool & Smart Mapping
- Archive all data. Log events and errors
- Telemetries and Telecommands with MMI

- Electrical IF:
  - SpaceWire protocol
  - RS422
  - Analogue & Digital Acquisition + FPGA tachometer
  - Current Outputs for SAS



EGSE

HW Elements

1. PXI Chassis & PXIe8840 Quad Core
2. SPW 4 port board
3. Sync PXI-6683H
4. NI PXI 6230 Multifunction DAQ
5. NI 4322 Analog Output
6. NI 7691 FPGA & NI 6581 I/O
7. NI PXIe 8431/8

1. PXI 8840 Quad Core

1. PXI Chassis

2. SPW INS, STR, GNSS

3. 6683H - Sync

4. 6230 - RW

5. 4322 - SAS

6. 7691 + 6581 Tacho

7. 8431 – RS422 RCS OSM + REM, ELEV, FADS

EGSE

Interfaces

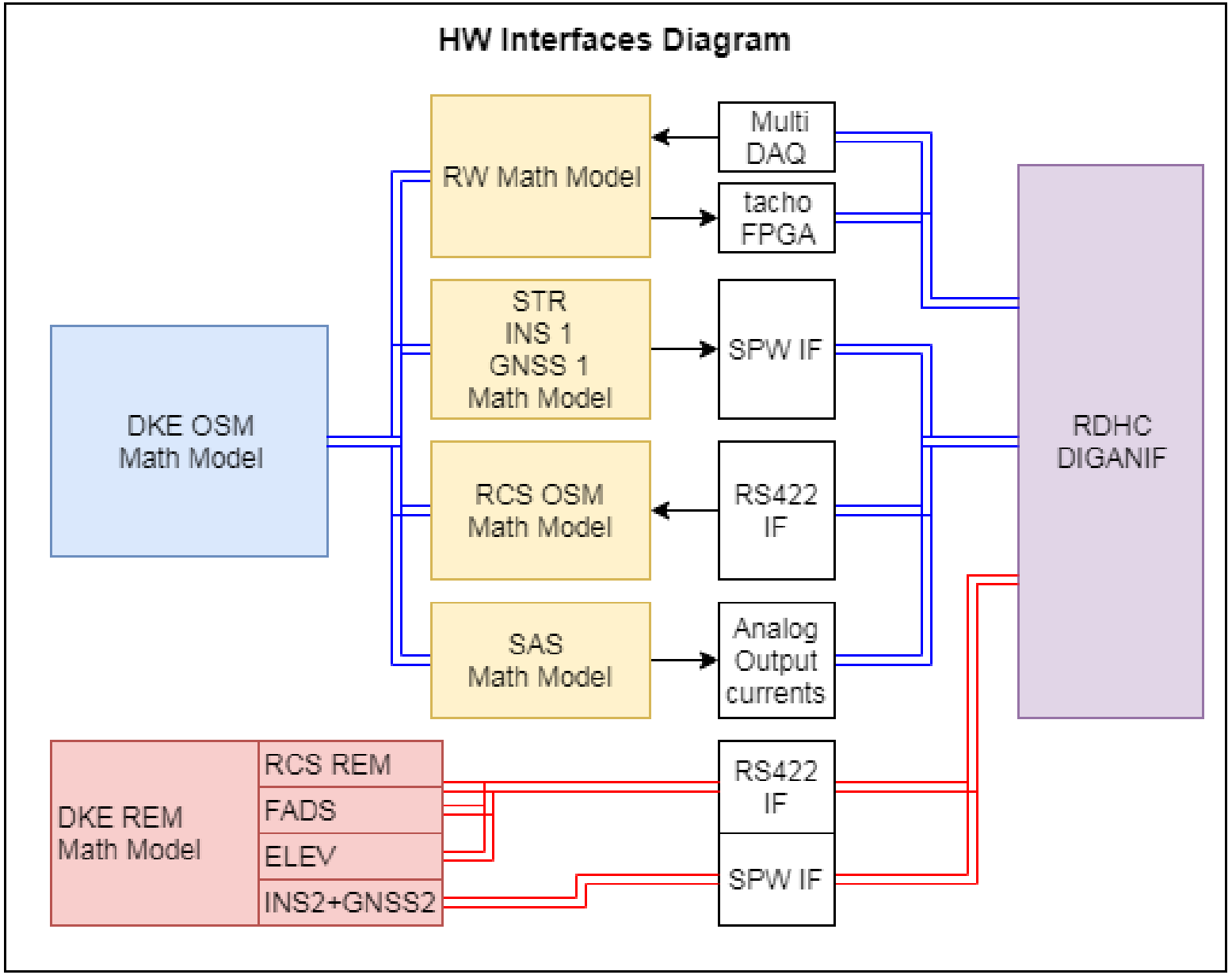
2 different designs for 2 different phases:

OSM Phase

- ✓ DKE OSM Math model
- ✓ Sensor & Actuators math models
- ✓ Electrical IF for every unit / model

REM Phase

- ✓ DKE REM Math Model containing sensor and actuators models.
- ✓ Electrical IF for every unit / model



EGSE

HW MAtrix

Board Model	Board Name	SW Module	Signal	Interface
PXIe-8840-RT	PXI Controller	MMI-IF	TMTC	MMI Host Computer
		STR	LAN	STR OGSE
PXI-6683H	Synchronisation board	GNSS	PPS	RDHC
PXIe-8431/8	RS-422 Board	OSM RCS	RS422	RDHC
		REM RCS	RS422	RDHC
		ELEVON	RS422	RDHC
		FADS	RS422	RDHC
SpW PXI interface	SpaceWire Board	INS	SpW	RDHC
		STR	SpW	RDHC
		GNSS	SpW	RDHC
PXIe-4322	Current Output Board	SAS	AO	RDHC
PXIe-7961R + NI 6581	Digital Input/Output Board	RW	DO	RDHC
PXI-6230	Analogue Input Board	RW	AI	RDHC
		RW	DI	RDHC

EGSE
Interfaces

NI PXIe8431/8 - RS422

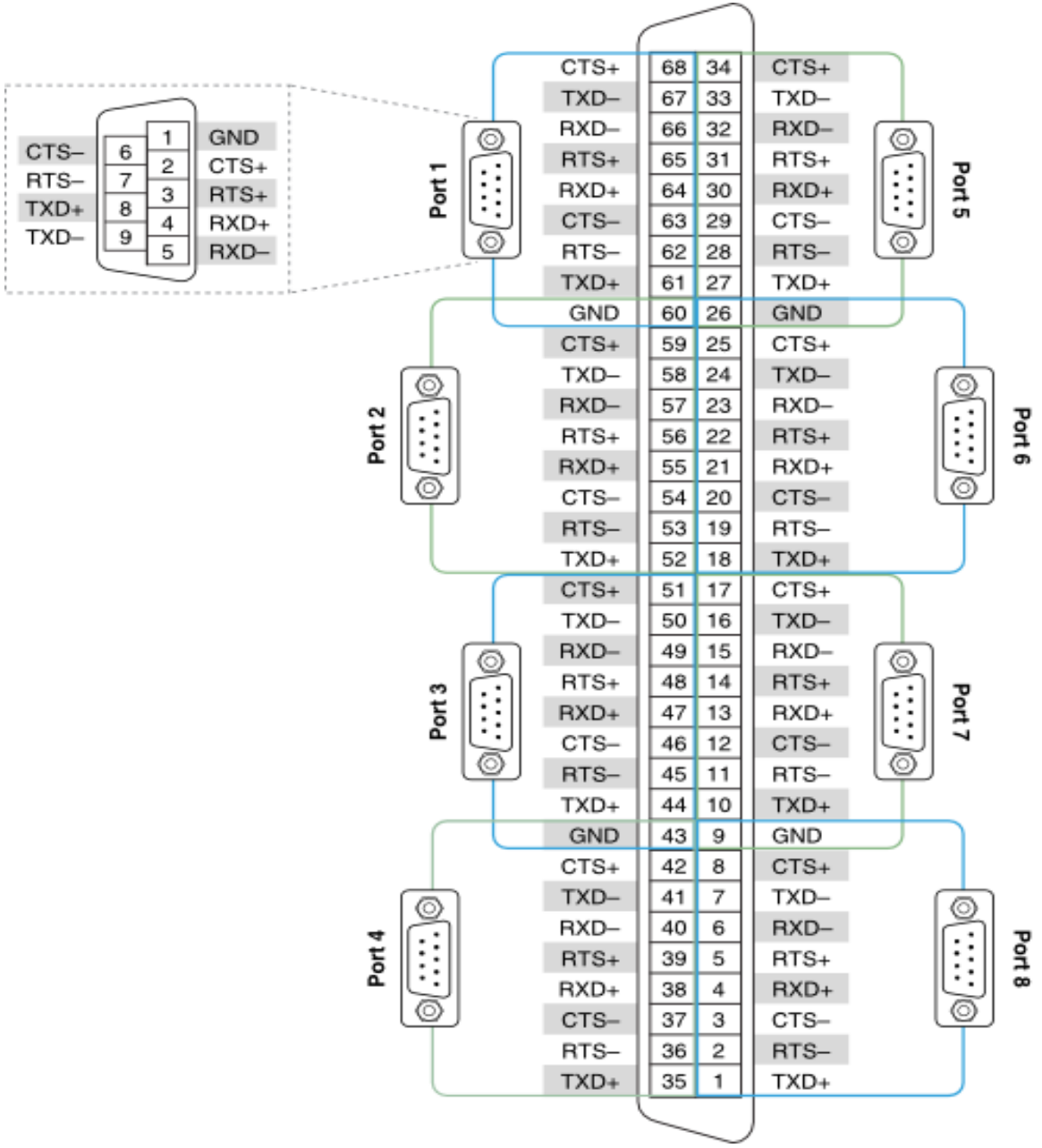
RCS OSM @ 4 Hz & REM @ 20 Hz
- ✓ Shared Electrical IF
- ✓ Port 0 pinout, 68-60 pins

ELEVON @ 20 Hz
- ✓ Port 1 pinout, 60-52 pins

FADS @ 20 Hz
- ✓ Port 2 pinout, 51-43 pins

Parameters introduced by Labview VISA Driver

Start Bit	Data Bits	Parity Bit	Stop Bit
0	1-8	9	10
0	Data Bits	ODD	1 Bit



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EGSE
Interfaces

SPW 4 port board

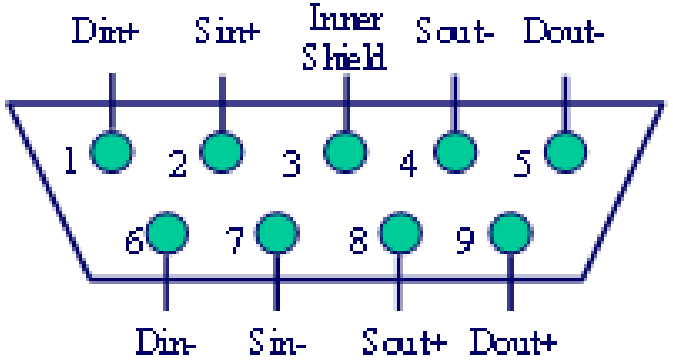
INS 1 & 2 @ 200 Hz
✓ Shared Electrical IF
✓ Port 0 pinout, 68-60 pins

STR @ 4 Hz
✓ Port 1 pinout, 60-52 pins

GNSS 1 & 2 @ 1 Hz
✓ Port 2 pinout, 51-43 pins

SPW Added Header
✓ 4 Bytes added to match standard

Star Dundee PXI port assignation	SW Unit assigned
Port / Channel 1	STR
Port / Channel 2	INS
Port / Channel 3	GNSS



Spacewire Data Payload

SPW Data Header	GNSS Data Packet	
4 Bytes	56 Bytes	
0xFE020000	Message 1 (0-27)	Message 2 (28-55)

TOTAL 60 Bytes

EGSE

Interfaces

NI PXI-6230 M Series Multifunction DAQ - RW

Torque Acquisition

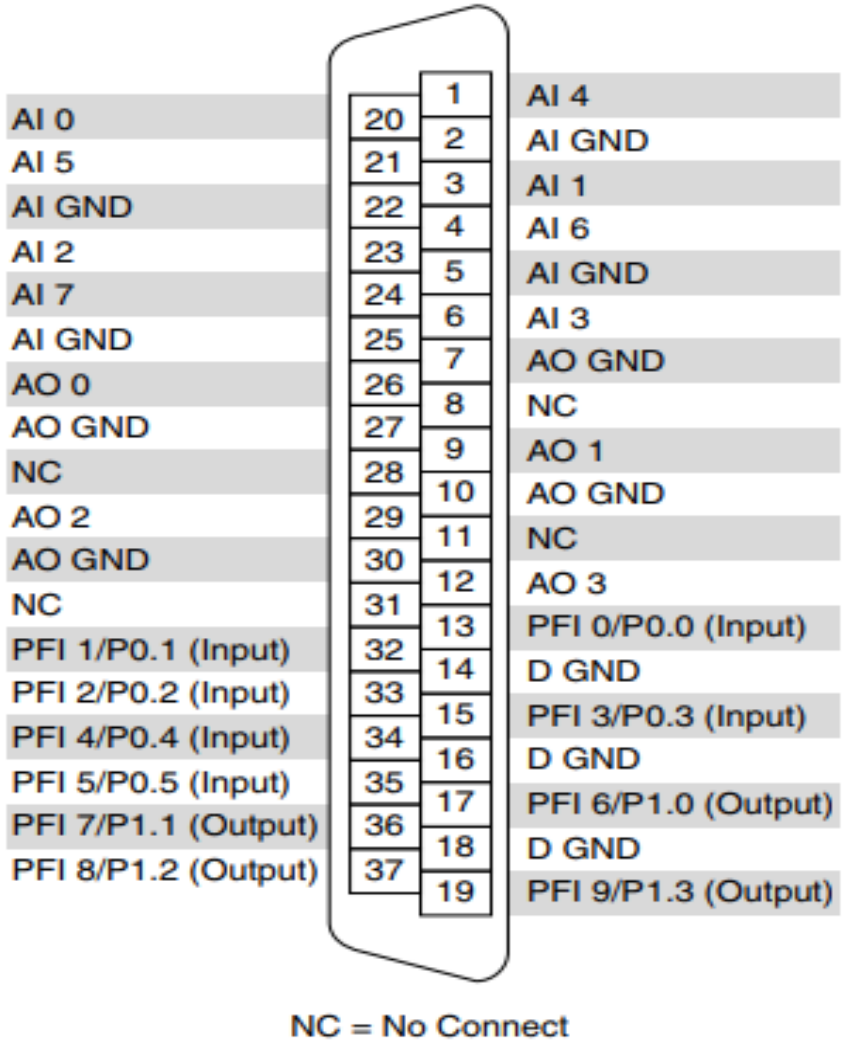
✓ Torque pins A0-A3

✓ Range 0 to 10V

Sign Acquisition

✓ Sign pins, PFI 1-4 (P0.0-P0.3)

✓ 0 to +0.8 V “low” / 2 to 5.5 V “high”



NC = No Connect

EGSE

Interfaces

NI-TB-4322 8 Ch. Analog Output. SAS

SAS 1 @ 200 Hz

- ✓ CH/ Cable 0 – 3
- ✓ Range 0 to 3.6mA
- ✓ Twisted pair cables

SAS 2 @ 200 Hz

- ✓ CH/ Cable 0 – 3
- ✓ Range 0 to 3.6mA
- ✓ Twisted pair cables

Channel / Cable	Connector type	Range	Frequency	Use
Channel / Cable 0	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 1 Current 0
Channel / Cable 1	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 1 Current 1
Channel / Cable 2	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 1 Current 2
Channel / Cable 3	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 1 Current 3
Channel / Cable 4	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 2 Current 0
Channel / Cable 5	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 2 Current 1
Channel / Cable 6	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 2 Current 2
Channel / Cable 7	Shielded twisted pair cable	0 to +3.6 mA +/- 10%	200 Hz	SAS 2 Current 3

EGSE

Interfaces

NI 6581 for FPGA. Tachometer

Tacho signal

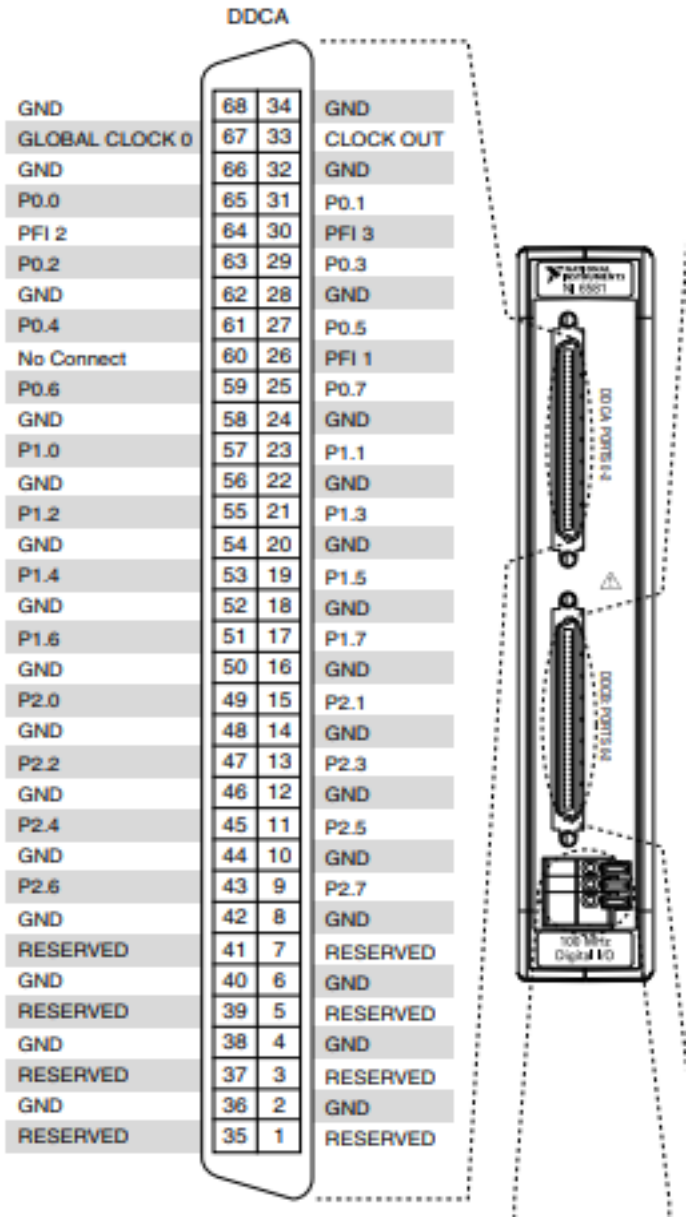
✓ DDCA P0.0 – P0.3 for RW1 - RW4

✓ 0 V for “0” / 3.3 V for “1”

Tacho sign

✓ DDCA P0.4 – P0.7 for RW1 - RW4

✓ 0 V for “0” / 3.3 V for “1”



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EGSE
Interfaces

Sync Board NI PXI 6683H

Port 0

- ✓ PFI 0
- ✓ SMB Cable
- ✓ 0V “typical low” / 3,3V “typical high”
- ✓ 1 Hz PPS for GNSS

Channel / Port	Connector type	Range	Frequency	Use
PFI 0	SMB 210 Cable, Dual SMB Plug to Dual SMB Plug Coax, 50 Ohm.	0V “typical low” / 3.3V “typical high”	1 Hz	1 Hz PPS for GNSS

PFI<0..2>

Output Characteristics

Frequency range ..... DC to 50 MHz

Output impedance ..... 50 Ω, nominal

Output coupling ..... DC

Output voltage levels

- Output high ..... 1.2 V min, 1.6 V typical for 50 Ω load to ground
  2.6 V min, 3.3 V typical for 1 MΩ load
- Output low ..... 0.1 V max, 0 V typical for 50 Ω load to ground
  0.1 V max, 0 V typical for 1 MΩ load

Absolute maximum applied voltage[1] ..... 0 to 4.4 V

Output-to-output skew, asynchronous
PXI_STAR to PFI routes[2] ..... <400 ps, typical

Output-to-output skew,
other asynchronous routes ..... <1.5 ns, typical

Output-to-output skew, synchronous routes ..... <2 ns, typical

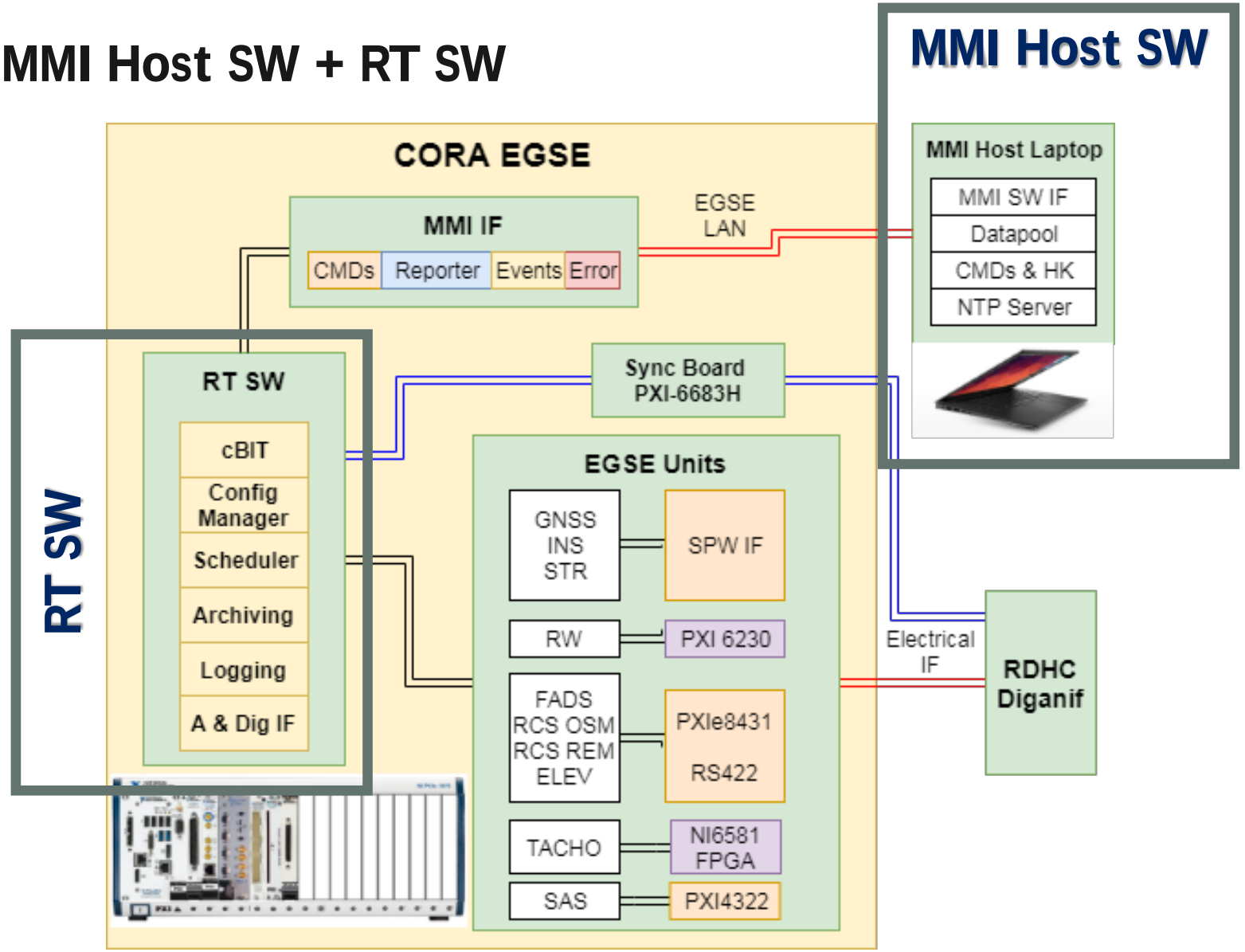
Synchronized trigger clock
to out time, t_{co} ..... 10 ns, max (relative to CLKOUT when configured to route PXI_CLK10)

Output current ..... ±48 mA, max

Square wave rise/fall time
(10 to 90%) for 50 Ω load ..... <1 ns, typical

EGSE

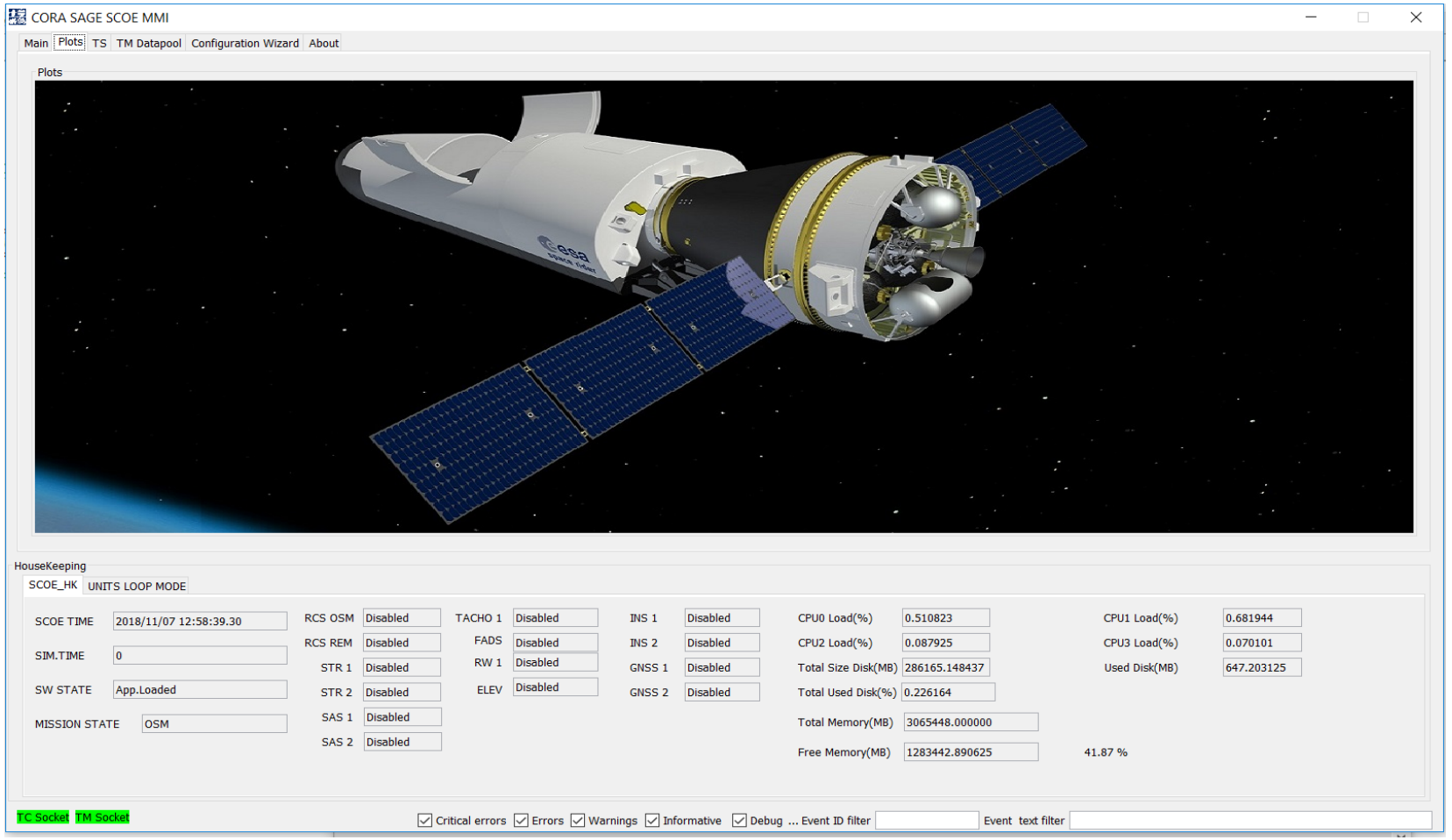
SW Elements: MMI Host SW + RT SW



EGSE

SW Elements: MMI Host SW + RT SW

1. Main Front Panel
2. Plots
3. Test Sequence
4. TM Datapool



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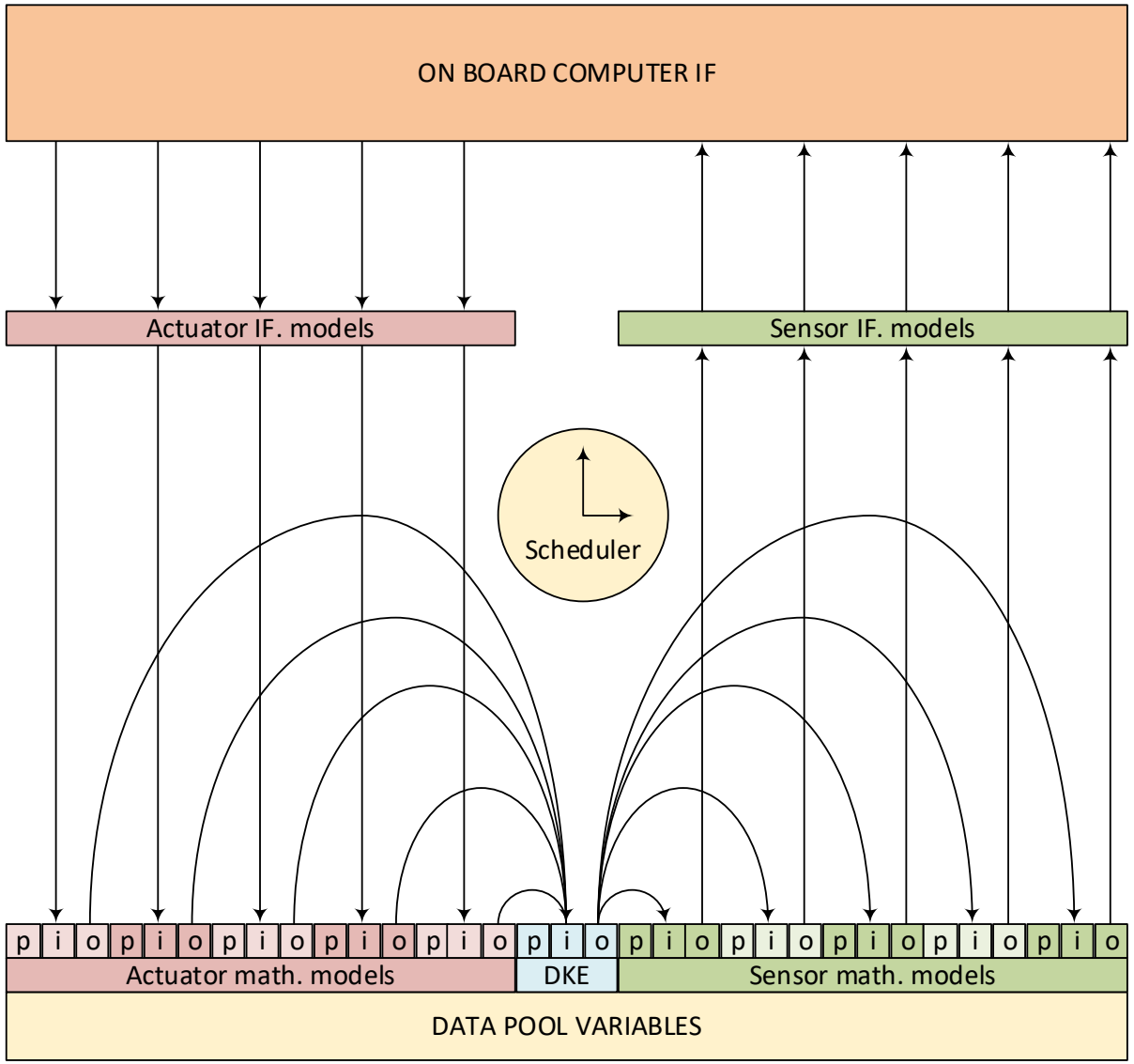
EGSE

SW Elements: MMI Host SW + RT SW

EGSE

SW Elements: MMI Host SW + RT SW

- Built In Test
- Model Initialization
- Global Datapool
- Scheduler
- Error Injection
- Log / Archive
- MMI I/F
- Model replacement



CoRA SAGE
Star Tracker Unit

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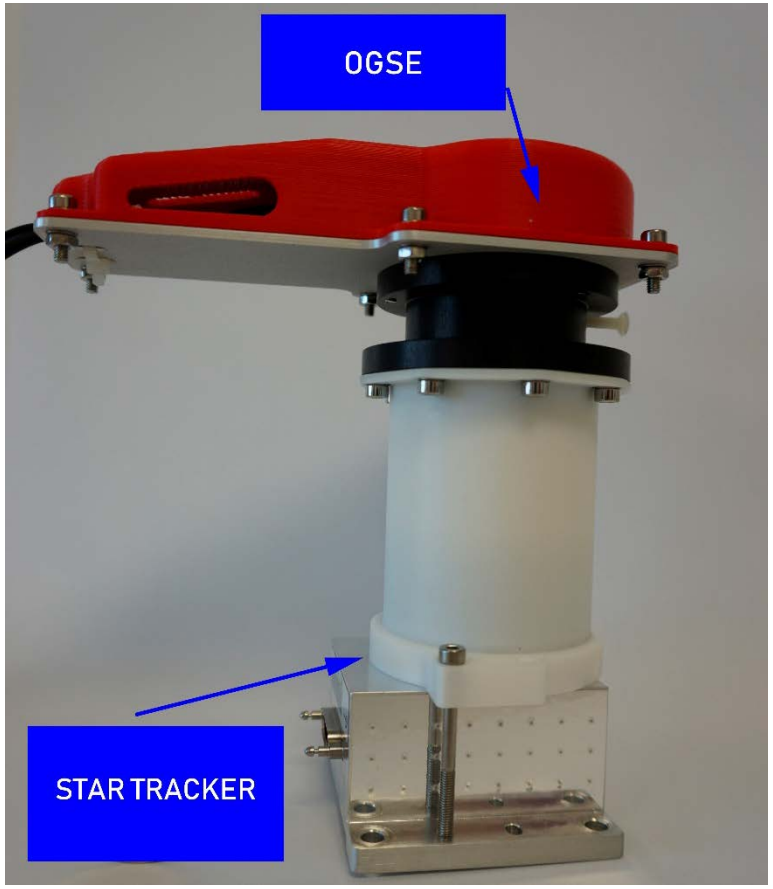
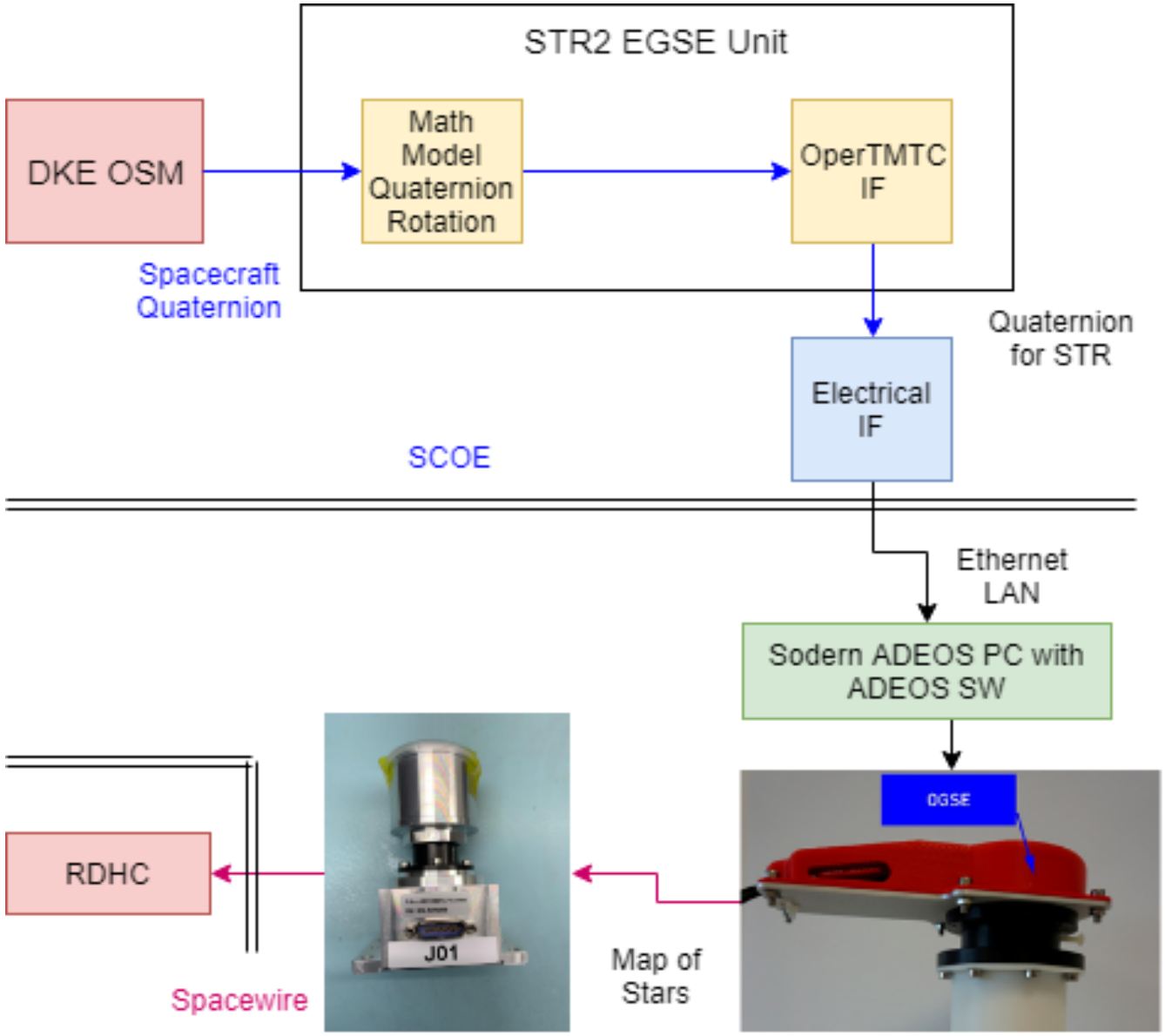
Star Tracker Unit

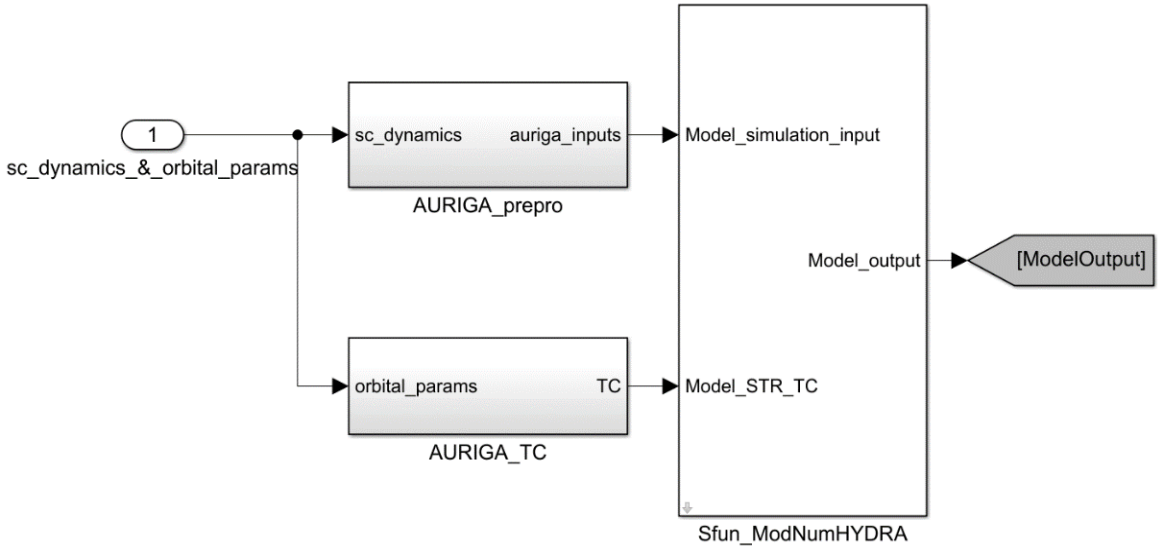


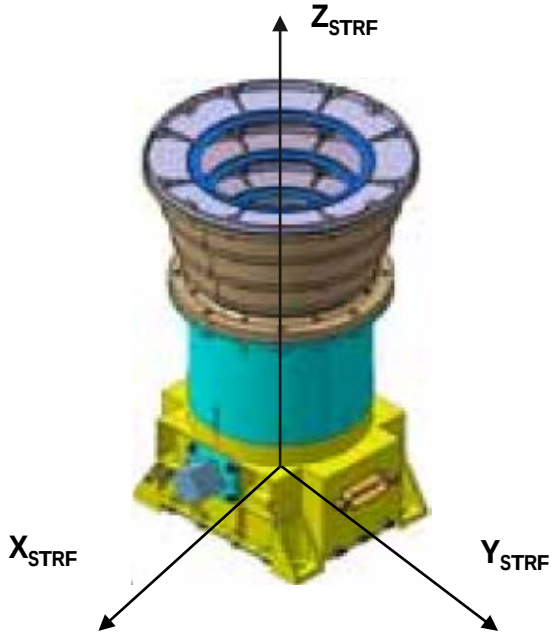


Star Tracker Unit

AOCS/GNC Units – AURIGA STR

- STR x1 (Engineering Model)
- Redundancy by Mathematical Model
- AURIGA Simulink model provided by Sodern.
- Performances of the attitude tracking mode of the STR.





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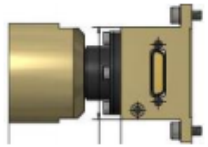
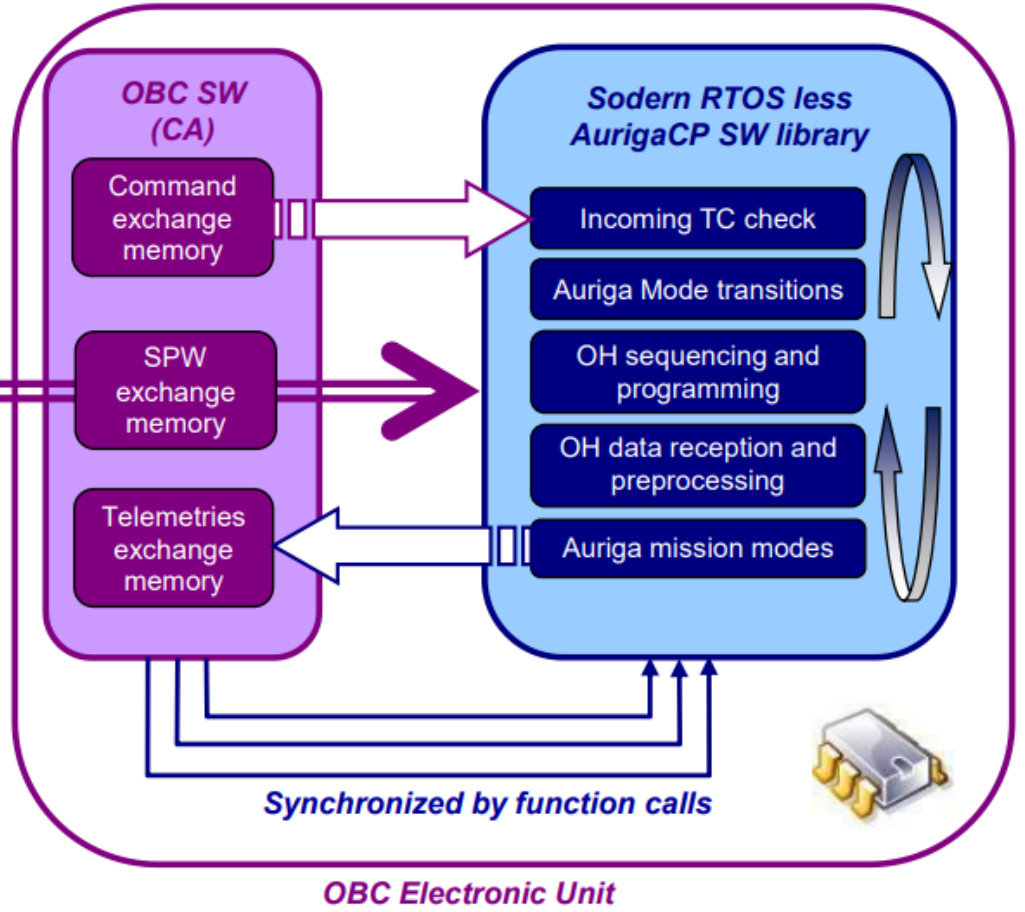
Star Tracker Unit
AURIGA STR SW

The OBC SW (running in RDHC) controls the AURIGA STR.
Examples:



Auriga OH designed by SODERN



- TC execution
- Optical Header Parameters Configuration
- OH synchronization
- Management of mission modes
- Collection of TMs

Along with the OH, a SW library supports this operations.

CoRA SAGE Validation

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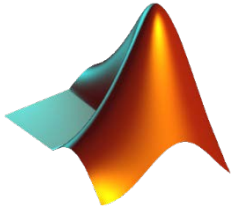
Validation

AOCS Modes



[CoRA SAGE FES]

Orbital Modes

Re-entry Mode

taste
The Assert Set of Tools for Engineering

Design

Conversion to Fixed Point

Performances

Autogenerated code

Interfaces with OBSW

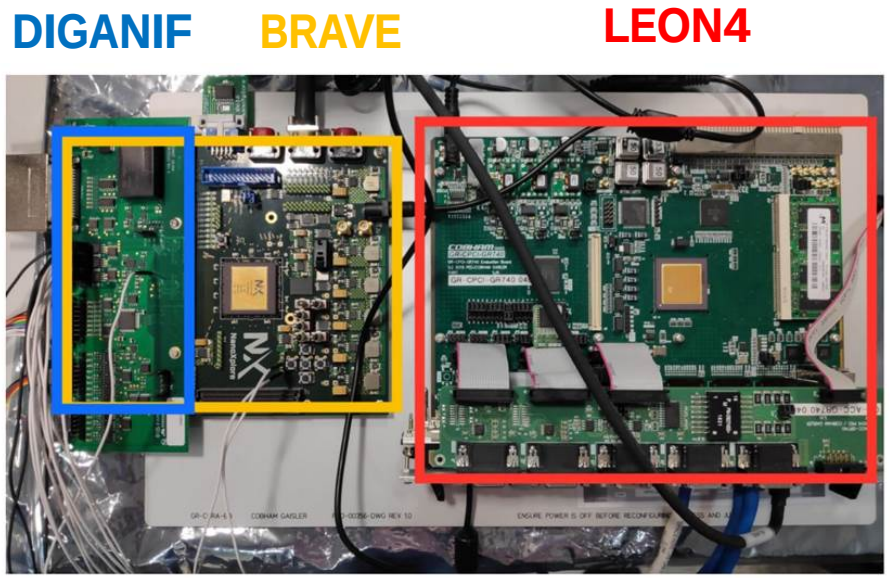
Embedding into final target

Functional Engineering Simulator

Validation

EGSE functionalities, performance and IF

- **Functionalities**:
  - MMI test conduction
  - Logging and reporting
- **Performances**: real time – close loop & open loop
- **Interfaces**:
  - Spacewire
  - RS422
  - Analogue & Digital Acquisition + FPGA tachometer
  - Star tracker interfaces
- **Star tracker in the loop**



- **In BB side:**
  - Dedicated driver per IF to communicate with EGSE, frequency register

Validation

Integration and Test Flow

AOCS/GNC in FES

- Set of AOCS/GNC SW simulation case in Matlab/Simulink

AOCS/GNC in TASTE

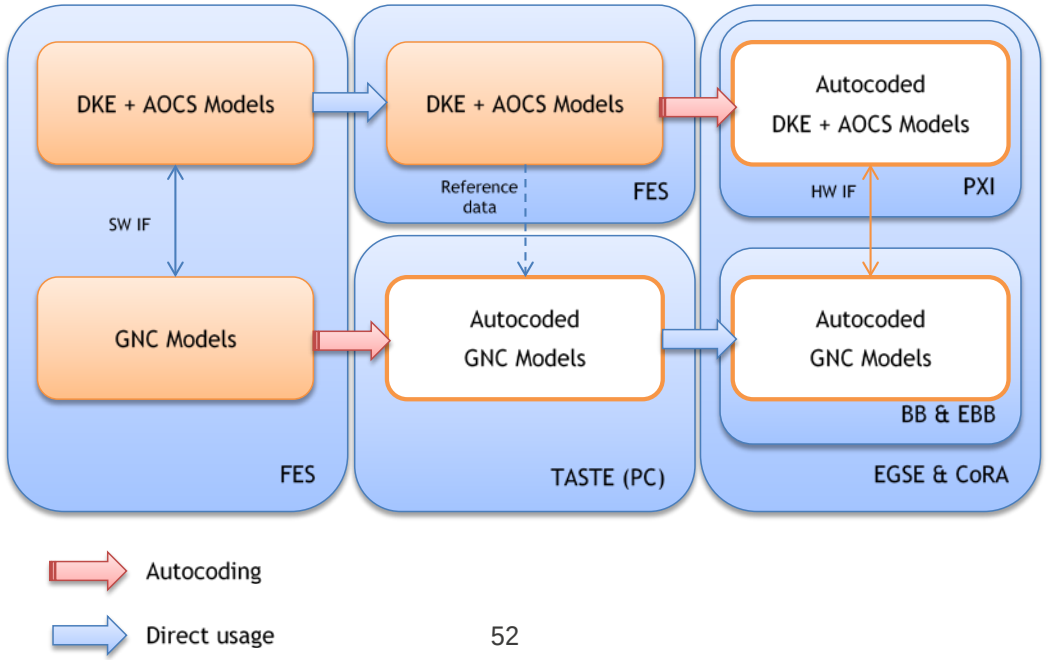
- AOCS/Modes and algorithms autocoded in the target platform
- Subset of AOCS/GNC tests

CoRA-SAGE EGSE

- verify the HIL closed loop features with the RDHC BB
- Subset of AOCS/GNC tests

System test at CoRA level

- final verification phase will take place at the ESTEC Avionics Lab with the Elegant BB



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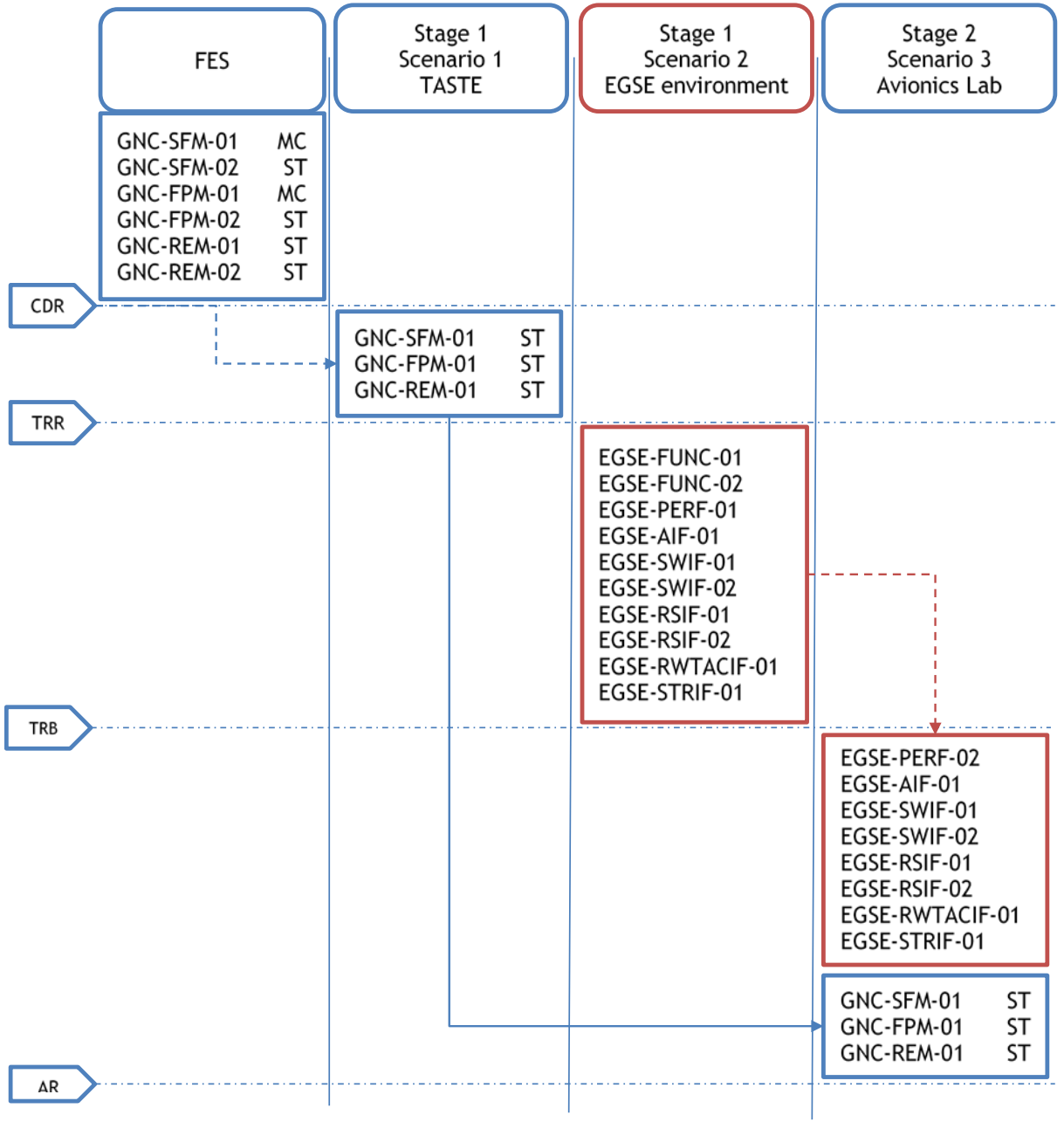
Validation
Test Flow

- Only a selection of Tests is flown down to the next review/facility
  - Blue is GNC
  - Red is EGSE



CoRA SAGE Testing

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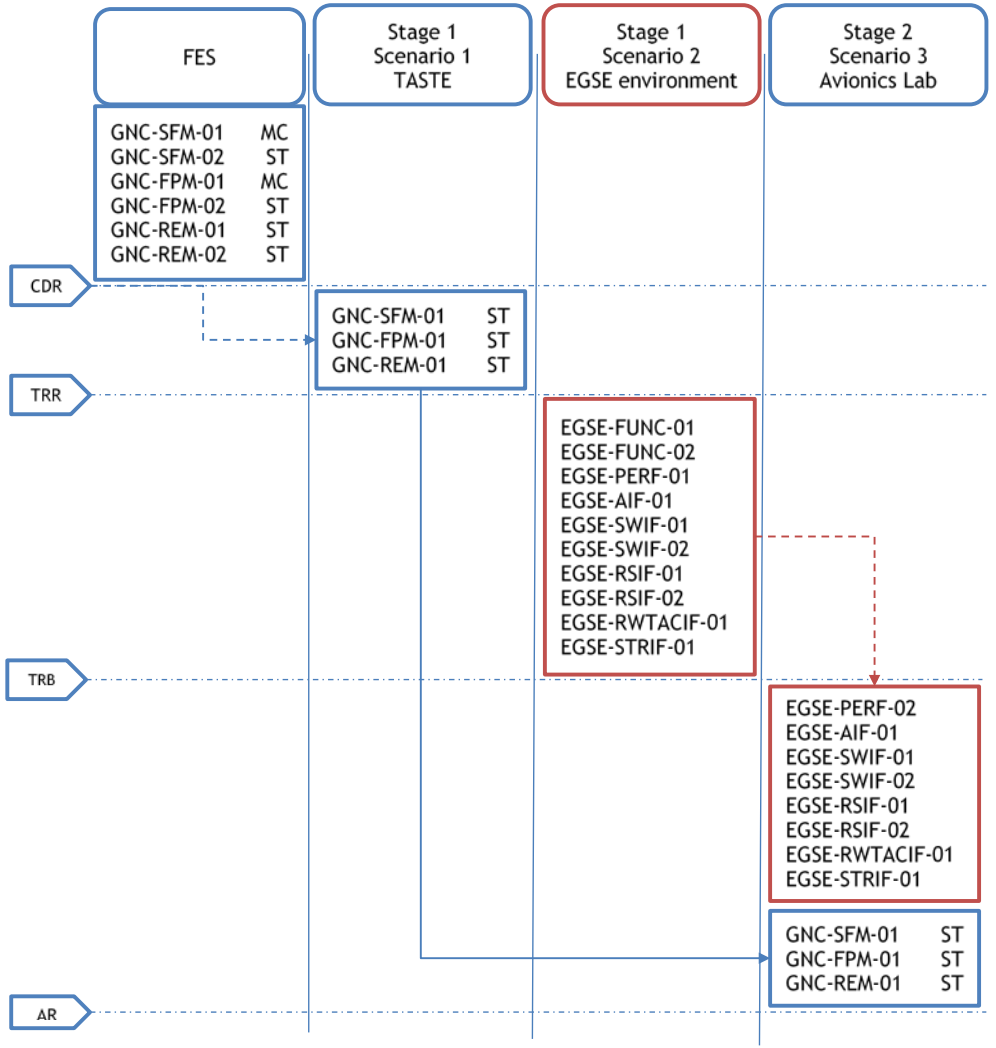
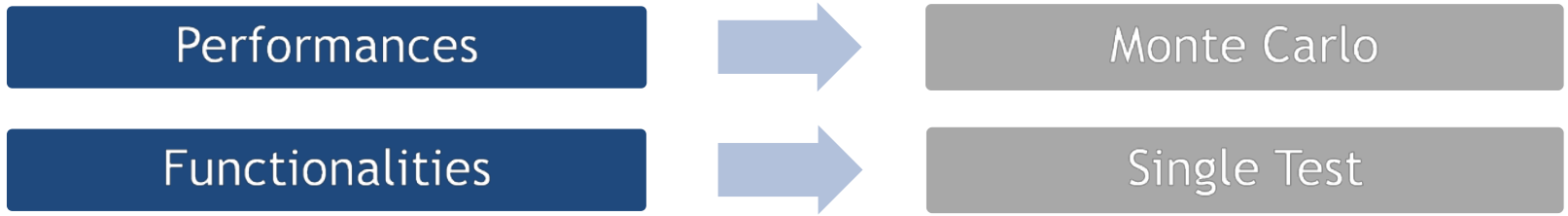
Testing
Status

- All SAGE products have been successfully validated in an isolated way while the RDHC and MBAD products were still under development
- Close loop testing on progress and to be completed in the coming weeks before the final integration in the ESTEC Avionics Lab



Testing

SAGE AOCS/GNC Tests



- SFM-01: Sun Pointing (MC)
- SFM-02 – Eclipse Transition (ST)
- FPM-01: Fine Pointing (MC)
- FPM-02: Mode Transition (ST)
- REM-01: Nominal Re-entry
- REM-02-1: FADS Aero-Angles fault
- REM-02-2: FADS Mach number fault
- REM-02-3: FADS complete sensor failure
- TASTE Deployment
- TASTE Deployment on GR740

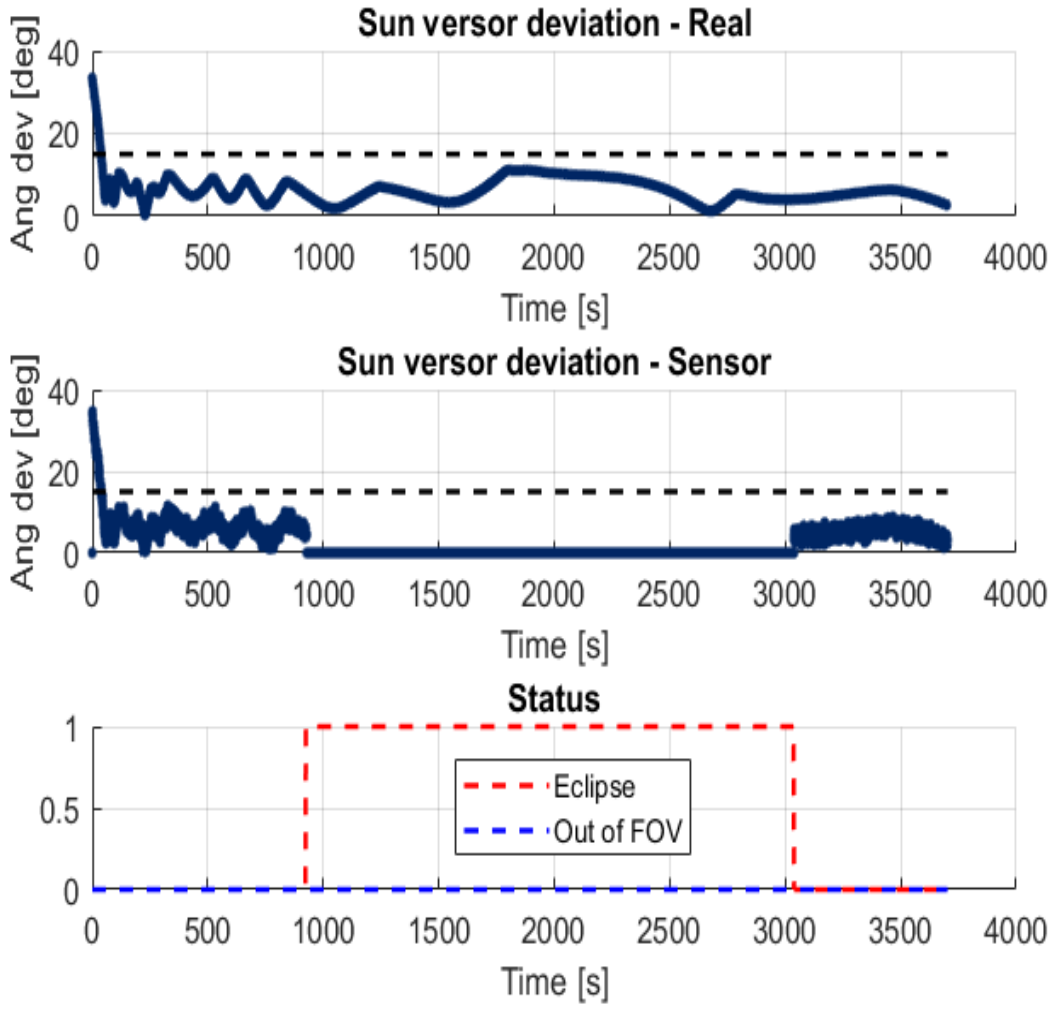
Testing

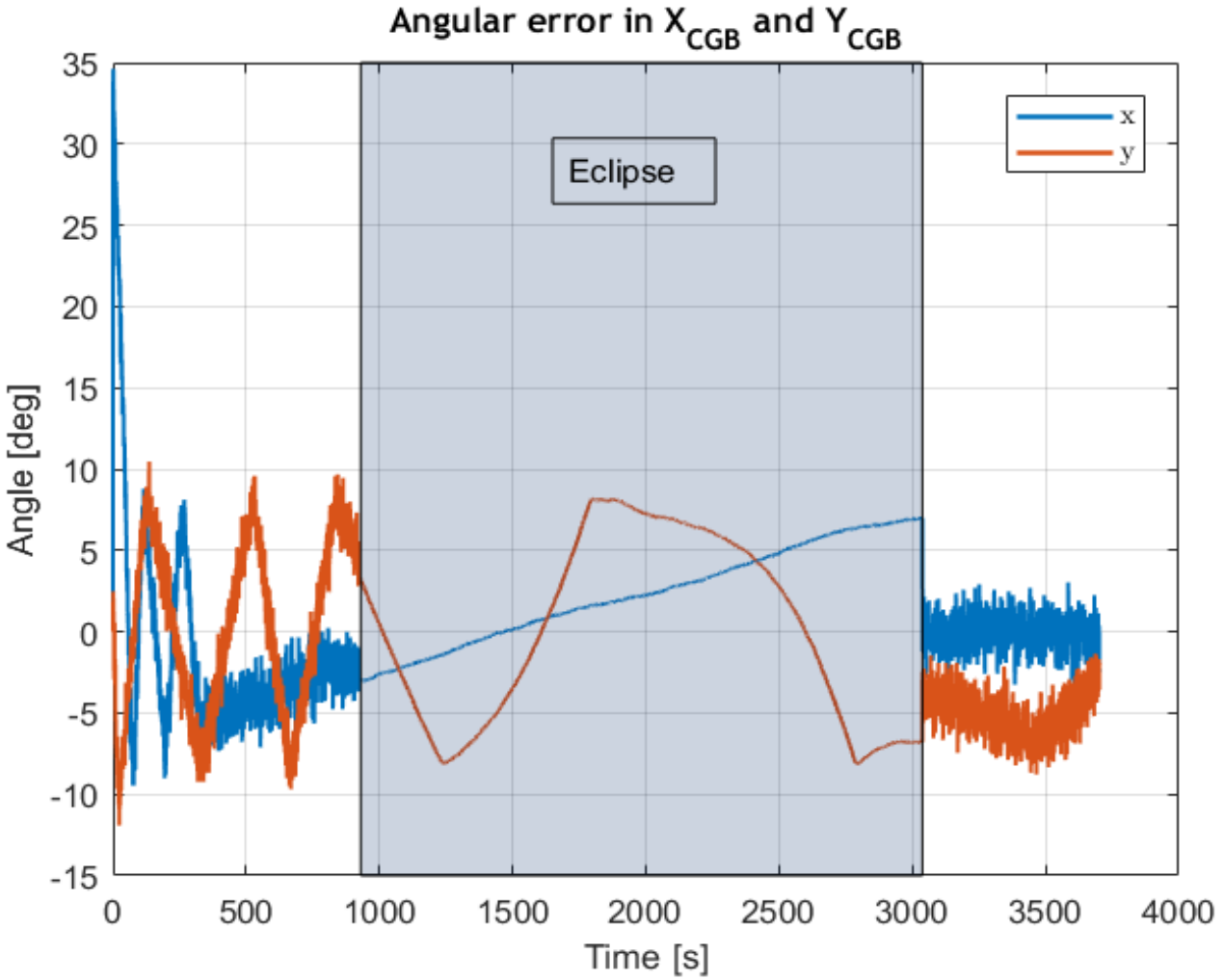
SAGE EGSE Tests

- Functional: SW reuse.
  - EGSE-FUNC-01: Test conduction
  - EGSE-FUNC-02: Autonomous logging and reporting
- Performance: Closing the loop is needed
  - EGSE-PERF-01: Real Time performance test. Open Loop
- Interfaces: with EGSE in standalone.
  - EGSE-AIF-01 Analog IF test
  - EGSE-SWIF-01 SpaceWire IF test in FPM
  - EGSE-SWIF-02 SpaceWire IF test in SFM
  - EGSE-RSIF-01 RS-422 IF REM test
  - EGSE-RSIF-02 RS-422 IF OSM test
  - EGSE-RWTACHOIF-01: RW and TACHO IF test
  - EGSE-STRIF-01 STR IF test

Testing
Some examples

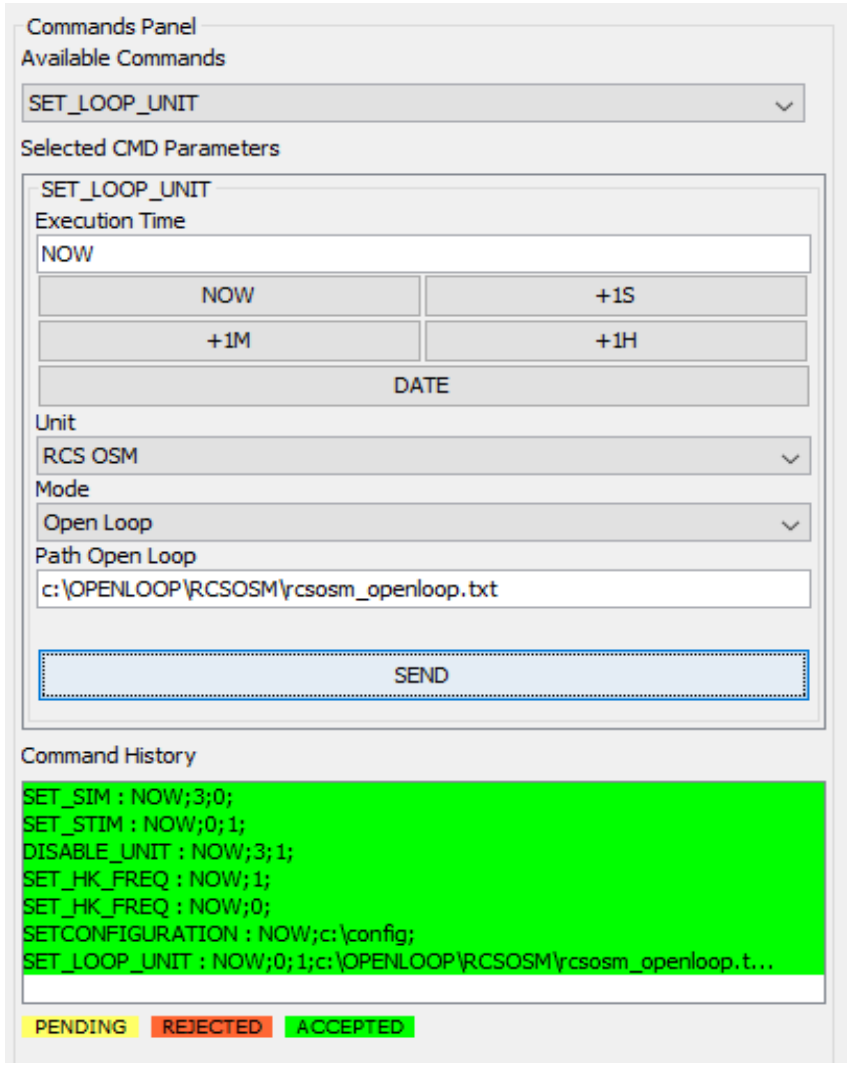
SFM-02 – Eclipse Transition (ST)

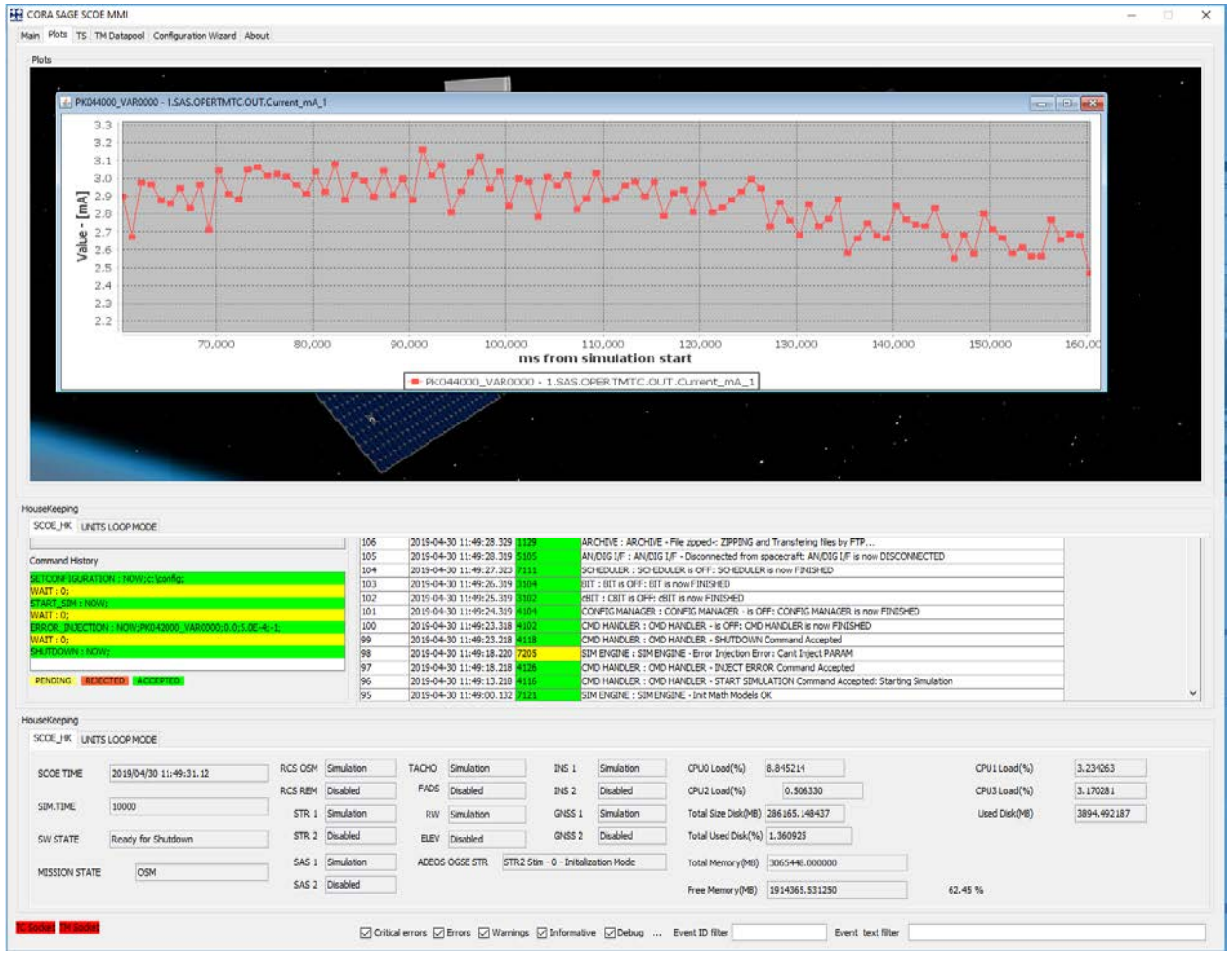




Testing
Some examples

EGSE-FUNC-01-MMI: Test conduction functionality





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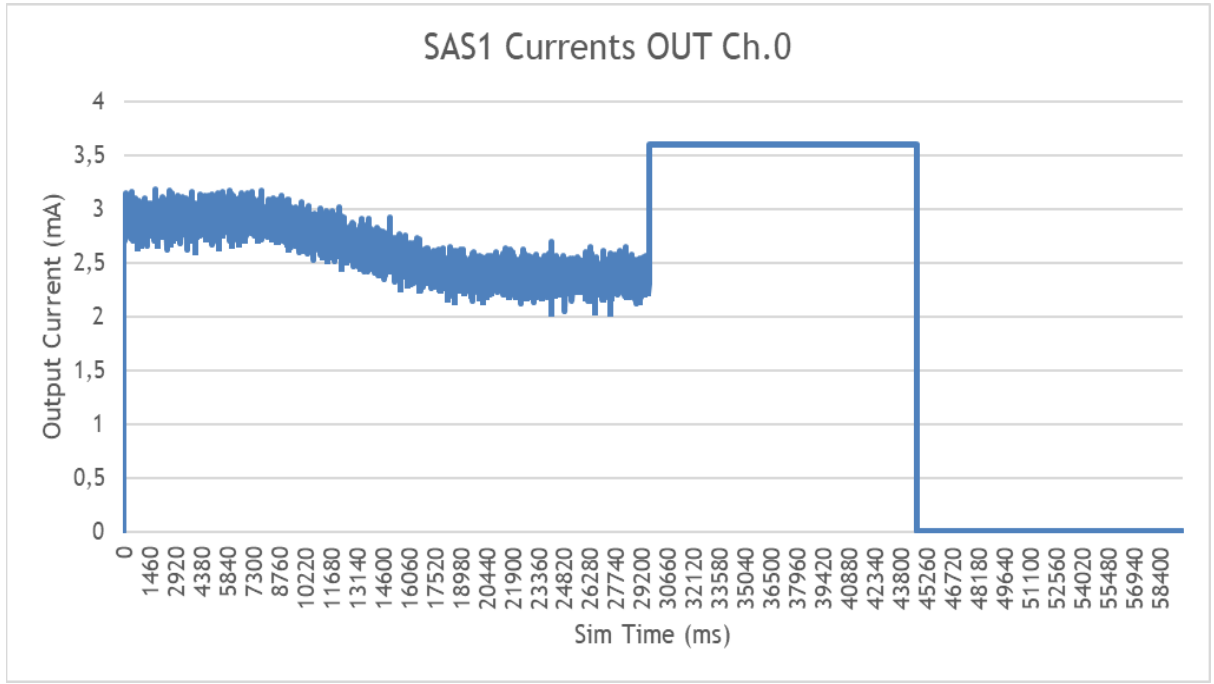
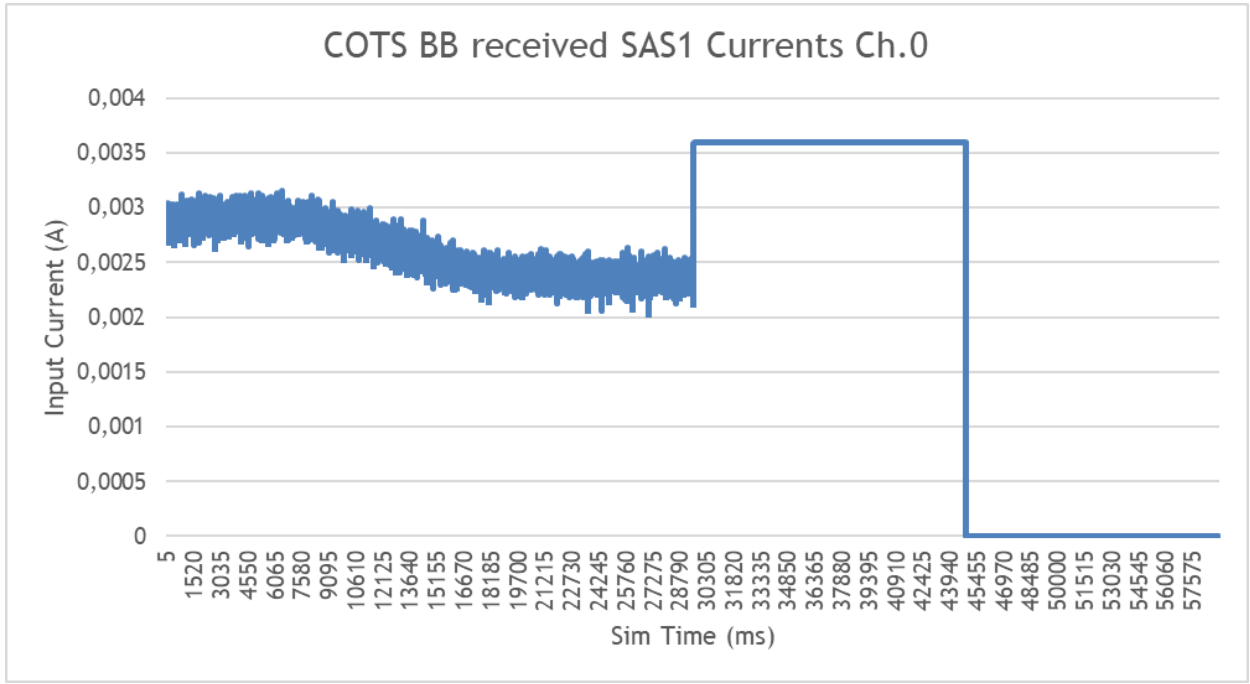
Testing
Some examples

EGSE-AIF-01: Analog IF test



Sent by EGSE



Received by COTS BB

CoRA SAGE
Conclusions and Next steps

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Conclusions and Next steps

✓ **TRB successfully completed on April 2019**:

- ✓ EGSE is validated
- ✓ AOCS/GNC modes validated in TASTE
- ✓ Star Tracker in the loop validated

❑ **Next steps**:

- ❑ Preintegration at SENER on going
- ❑ Final Integration of SAGE in ESTEC Avionics Lab

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THANK YOU

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