NAVISP 61: LUNAR NAVIGATION PAYLOAD DEMONSTRATOR

FINAL PRESENTATION

2025 09 16

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ThalesAlenia a Thales / Leonardo company Space

AGENDA:

- /// Introduction: NAVISP 61 Project context
- /// NAV P/L EBB
- /// VLBI: Transmitter on the Moon
- /// LRR
- /// WRAP-UP

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INTRODUCTION

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LUNAR NAVIGATION PAYLOAD KEY OBJECTIVES

The NAVISP-61 aiming at design and development a Lunar Navigation payload Demonstrator and relevant **EBB of critical elements** (e.g. SGU and the NAVANT). In addition, an EBB of the LRR and TT&C are also proposed.

The **NAVISP-61** can be considered as a **de-risking** for the design and development flight NAV Payload (Moonlight) and as an **Early demonstrator** for future payload performances**.**

Robust Development Approach

- Support pre-developments (EBB) and the early verification of the elements/modules

Lunar Environment

- The Navigation Payload is designed to deal with the operational requirements specific for the application

Size Weight and Power minimization

- Realization of small and light payload with the lowest possible power consumption

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MAIN GOALS OF ACTIVITIES

///Driving requirements

- Use of high TRL technology for individual components
- Re-use of GNSS techniques and, if in line with reduced SWaP, re-use of GNSS technologies
- Reduce SWaP

/// The activity aimed at developing **an Elegant BreadBoard**, including critical functionalities of the future flight payload models.

/// This EBB has provided a good indication/reference of the achievable performance for this payload and of the associated mass/power/size/environmental and interface requirements, as well as confirming the compliance against the LCNS system concept and system performance allocated to the navigation payload.

- **Understand in detail the critical functionalities of future navigation payloads on-board LCNS satellites, defining associated interface requirements;**
- **Develop of an Elegant Breadboard (EBB) of the critical components** of a generic Navigation payload demonstrator for future Lunar Communication & Navigation System (LCNS) orbiting satellites;
- **Assess achievable performance with a representative EBB unit**;
- **Reduce the implementation risk of the future models (EM/EQM/FM)** payload equipment by assessing the associated **critical technologies** in due-time and proposing an implementation roadmap for the navigation payload of the LCNS satellites and potential hosted payloads

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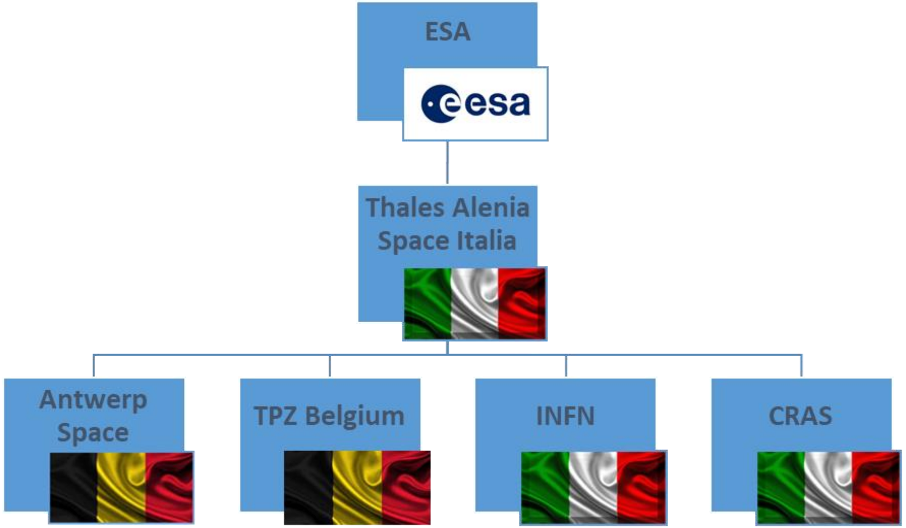
INDUSTRIAL ORGANISATION AND TEAM



ThalesAlenia Space (a Thales / Leonardo company)	Prime &technical coordination, responsible for Lunar Navigation Payload Design & Development, Qualification and test campaign, lunar system activities, NSGU, Antenna TX, GNSS receiver pre-developments., responsible for the on board definition and implementation of the OD&TS concept
TELESPAZIO (a LEONARDO and THALES company)	Responsible for Integration and Test of the Luanar Navigation Payload
antwerpspace (An OHB Company)	Responsible for the definition and pre-development of the VLBI for lunar satellite application
INFN	Responsible for the definition and pre-development of the Laser Retro Reflector for lunar satellite application
SAPIENZA Università di Roma – CRAS - “Centro Ricerca Aerospaziale Sapienza”	Contribution to System activities for the definition of OD&TS and releted application and performaces

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NAV P/L EBB

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AGENDA – NAV P/L EBB

- /// **Introduction (P. Salvatori)**
- /// **TT&C S/S (D.Gelfusa - TASI)**
  - /// Key Objectives and Main Achievements
- /// **Timing S/S (P. Salvatori/D.Cretoni - TASI)**
  - /// Key Objectives and Main Achievements
- /// **Navant S/S (P.Valle - TASI)**
  - /// Key Objectives and Main Achievements
- /// **SGU S/S (C.Ponzoni - TASI)**
  - /// Key Objectives and Main Achievements
- /// **EBB Integration and Testing (J. Crespo -TPZB)**
- /// **Conclusion (P. Salvatori)**

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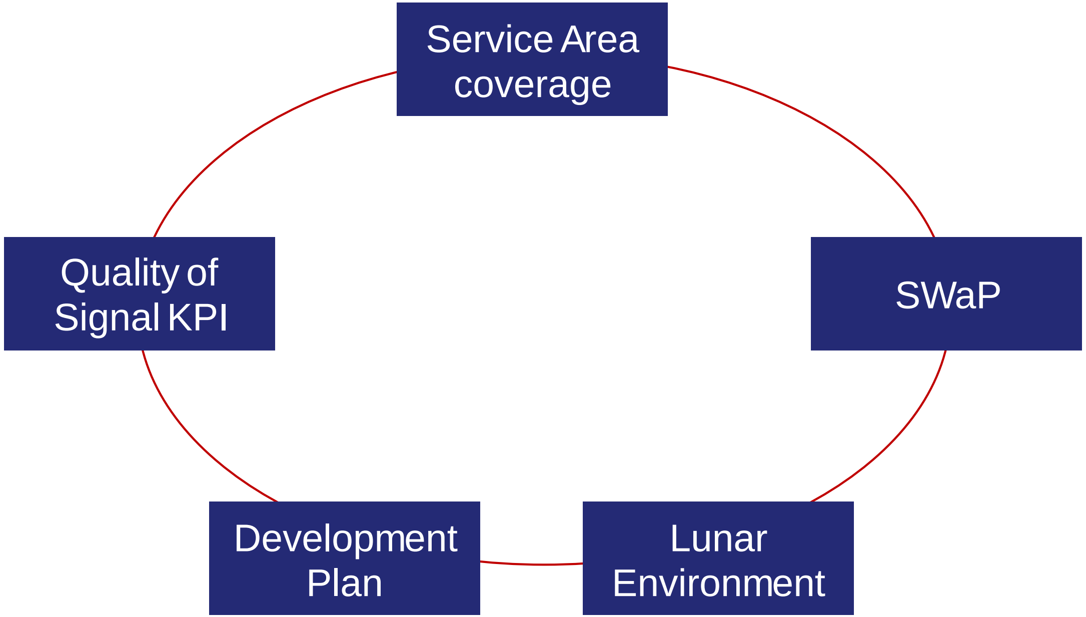
INTRODUCTION – THE NAVISP-61 PROJECT

Signal Waveform

One-way Ranging AFS		
Parameter	Data	Pilot
Initial Phase	0 deg	90 deg
Waveform	BPSK (1)	BPSK (5)
Chip-rate	1.023 Mchip/s	5.115 Mchip/s
Symbol Rate	500 Sps	N/A
Relative power	50%	50%

(*) New issue of LNIS standard has been realised during the project. The EBB made possible an early verification of the payload achievable performance

Main drivers and constraints



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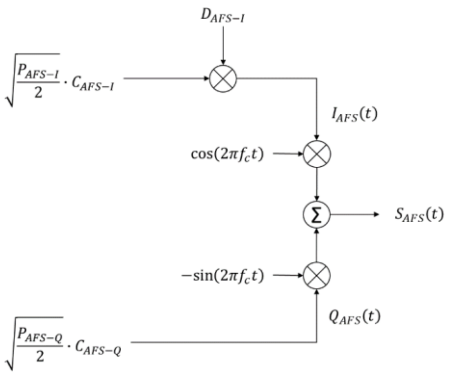
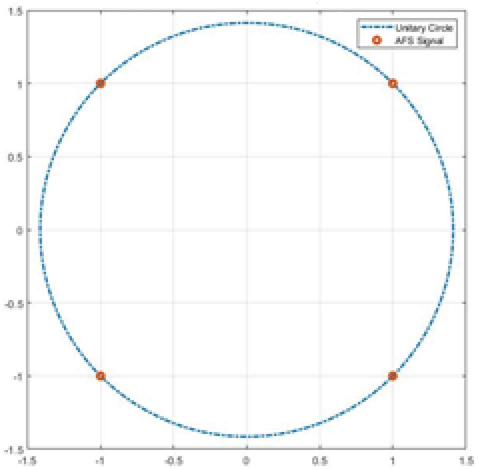
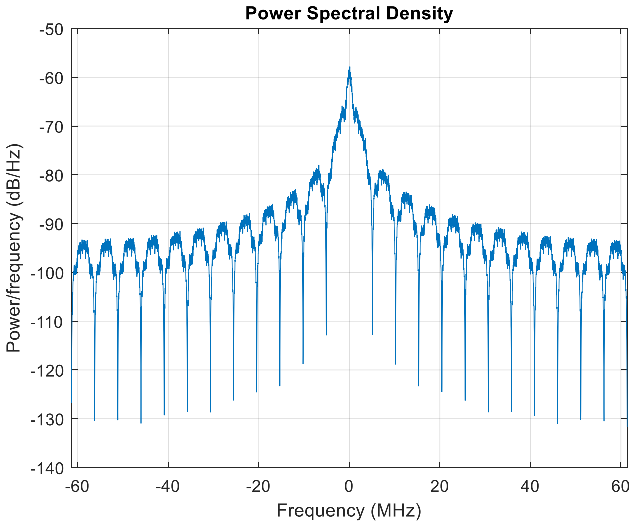
NAVIGATION SIGNAL CHARACTERISTICS

- The Navigation Signal in generation stage is obtained by two BPSK (one in phase and one in quadrature) with the same power level;
- Looking at the constellation plot it is possible to perceive as (at infinite bandwidth) the signal has a constant envelope and it is equivalent to a QPSK;







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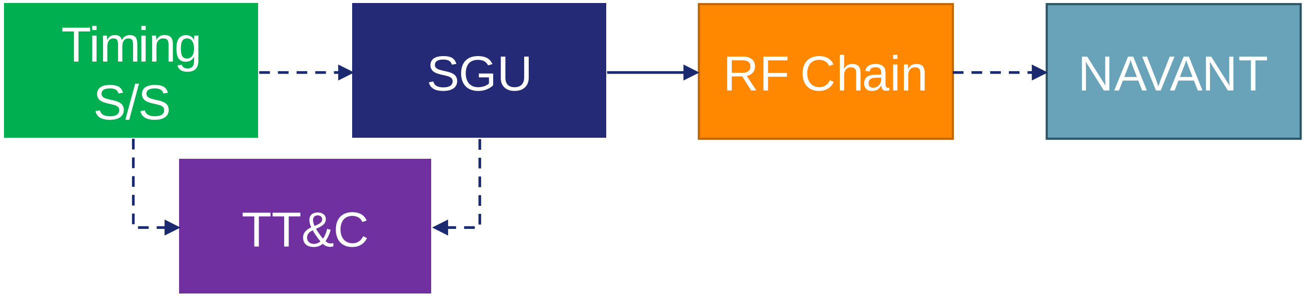
NAV P/L EBB

The Navigation Payload EBB is composed of 5 main sections:

- TT&C S/S
- Timing S/S
- Signal Generation Unit
- RF Chain
- NAVANT



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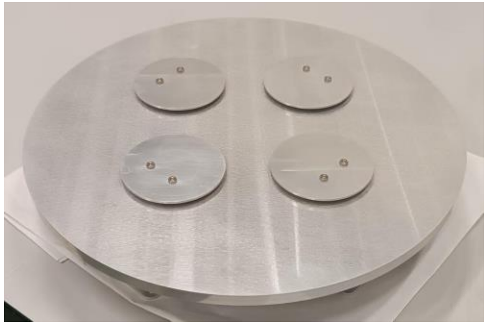
NAV P/L EBB DEVELOPMENT

In the framework of this activity the EBB of the TT&C, SGU and NAVANT have been developed. Timing S/S has been modelled through simulations while RF chain is implemented through external devices. Particularly, SSPA is a COTS device while for the RF Filter a custom development have been requested to the supplier.

SGU

TT&C



NAVANT

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TT&C

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SUMMARY

- In this activity a TT&C architecture supporting Telecommand, Telemetry, Ranging and Time-Transfer has been designed, including DSP algorithms able to fulfill the required time-transfer performances in terms of one-way jitter has been defined.
- A breadboard representative of the TT&C architecture has been designed and built, in particular for the main components and the digital signal processing implemented in the digital section.
- The breadboard has been tested to cover the critical functions i.e. spread-spectrum receiver and time-transfer.
- The breadboard has been completed with custom circuit implementing the required CDM-M transmitter to be used during the Spread-Spectrum receiver test campaign.
- Each building block has been tested separately at functional level and then the Final test campaign carried out the validation of the completed receiver and time-transfer functionalities and verifying the required performances, in details:

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TT&C: EBB DEVELOPEMENT

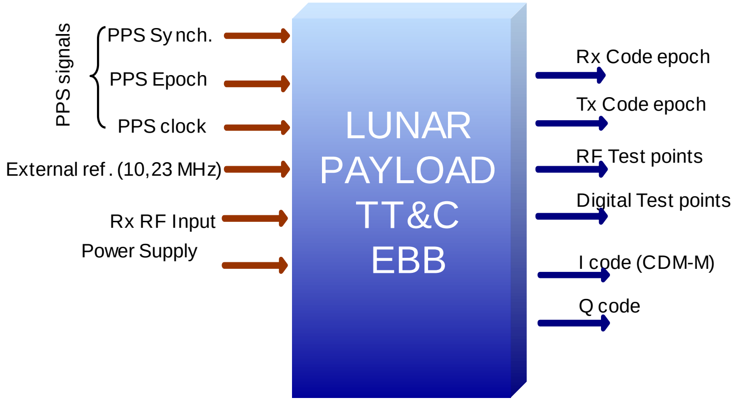
/// TT&C EBB is fully representative of the FM in terms of components and signal processing (test campaign covered spread spectrum receiving functions and time-transfer functions)

/// Custom functions for debug (i.e. CDM-M transmitter) has been implemented in FPGA

/// EBB is based on following components:

- LNA (evaluation board)
- Image rejection mixer (evaluation board)
- 1st IF Hybrid (custom board)
- S-BAND BPF (custom board)
- LNA (evaluation board)
- RF Transceiver (evaluation board)
- FPGA (evaluation board)
- Debug card (custom board)
- Interface card (custom board)

/// EBB I/Fs



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TT&C EBB TEST APPROACH

/// Test approach:

Test Plan

The test plan focused on time-transfer functions and all other propaedeutic functions (i.e. CDM-M transmitter, spread-spectrum receiver).

Preliminary activities before test campaign:

The following activities have been performed before test campaign;

- Specific analysis will be carried out in order to characterize the time-transfer performances in terms of one-way jitter considering key parameters (i.e. chip rate, C/N0, integration time).
- After characterization and trade-off resolution (complexity w.r.t. requirements), DSP architecture will be selected. The DSP design phase starts.
- Tests will start after new building blocks design, RTL verifications and integration.

Test campaign:

- Each building block has been tested separately at functional level.
- Final test campaign has been carried out in order to validate all required functionalities and performances evaluation of the complete time-transfer processing by characterizing the code epoch tracking jitter in worst case scenario

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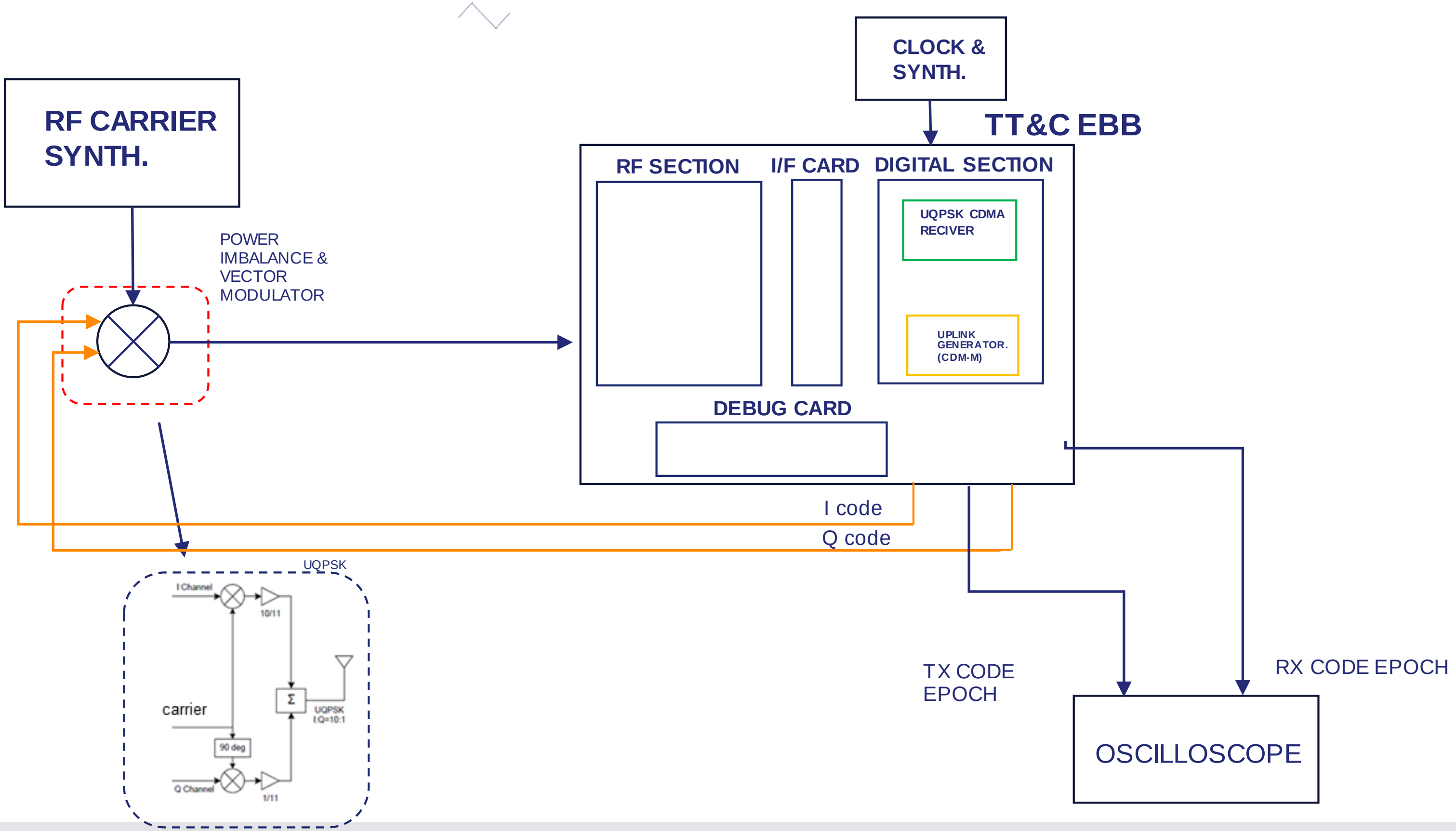
TT&C EBB TEST SETUP

/// Test bench block diagram



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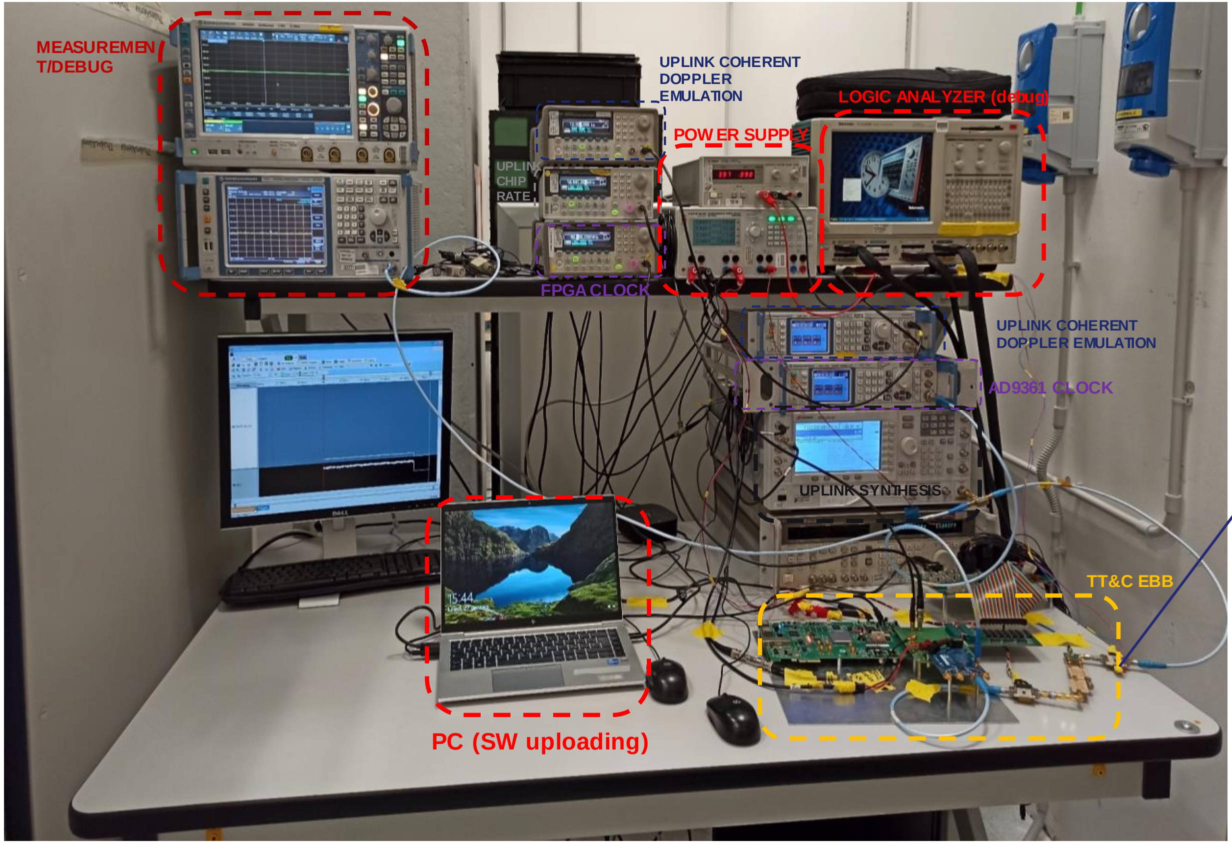
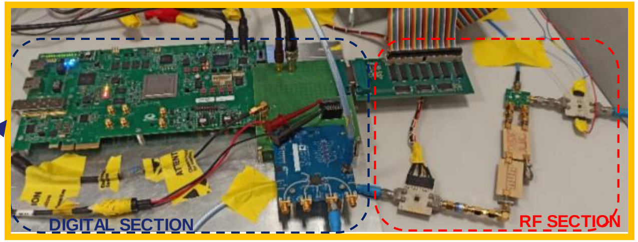
TT&C EBB TEST BENCH





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TT&C EBB TEST

Test ID	Test Description	Status	Remark
TC-EBB-PL-TT&C-0001	Uplink modulation verification	Completed - Passed	
TC-EBB-PL-TT&C-0002	Signal acquisition	Completed - Passed	
TC-EBB-PL-TT&C-0003	Signal tracking	Completed - Passed	
TC-EBB-PL-TT&C-0004	Telecommand BER	Completed - Passed	
TC-EBB-PL-TT&C-0005	AGC telemetry calibration	Completed - Passed	
TC-EBB-PL-TT&C-0006	Time transfer observables jitter	Completed – Passed*	Only CDMA (1 user) scenario @Puplink=-121dBm not passed (result sllightly higher than expectation)

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TIMING

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TIMING S/S- BASIC AND ADVANCED FM ARCHITECTURE

The timing subsystem baseline solution consists of:

•Space Atomic Frequency Standard (SAFS):
- ///1x active as main clock
- ///1x (or 2x) active as redundant clock

•Frequency Generation Unit (internally redundant):
- ///1x active
- ///1x cold redundancy

The satellite on-board clocks have the role to provide a stable and precise frequency reference signal (at 10 MHz).

The Master Frequency Reference signal at 10.23 MHz is then produced by a unit in charge to generate the on-board frequency reference starting from frequency reference signal provided by the atomic clocks. This is usually performed by a custom unit, the Frequency Generation Unit (FGU). This unit affords following functions:

- Handling capability of incoming atomic clock(s) signal;
- Monitoring&Control capability of atomic clock(s) signal;
- Phase offset Measurements;
- Phase & Frequency Control & Adjustment
- Master frequency reference signal (10.23 MHz) generation;
- Distribution to NAV Payload units

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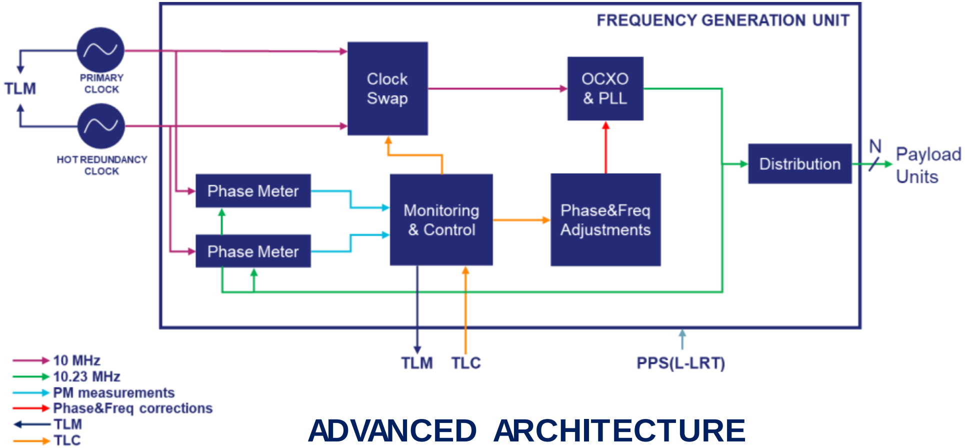
TIMING S/S- BASIC AND ADVANCED FM ARCHITECTURE

The BASIC architecture ensures the compliance with the requirements.

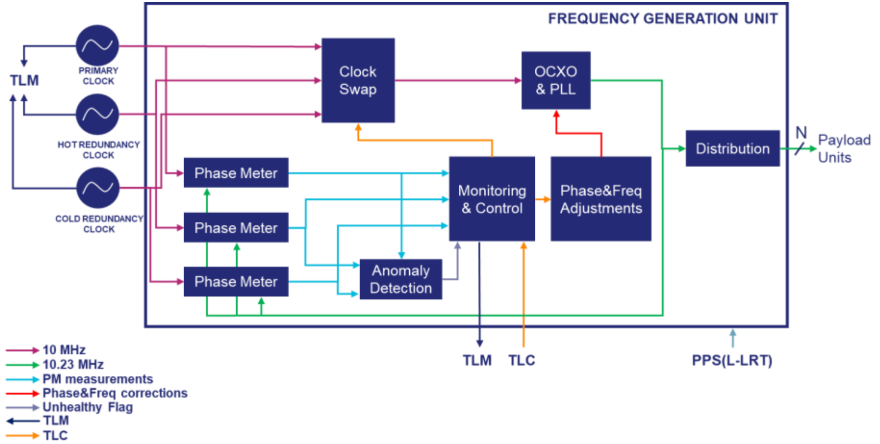
However, the advanced architecture offers more flexibility and more advanced functionalities (like the anomaly detection processed directly on-board).

Furthermore, the reliability is improved thanks to an additional clock in cold redundancy.

BASIC ARCHITECTURE



ADVANCED ARCHITECTURE



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ATOMIC CLOCKS TRADE-OFF

OCXO only (FGU's internal reference)

- Small SWaP (one order of magnitude more than CSAC)
- Worst performances

OCXO locked to CSAC

- Smallest SWaP (even including the power attenuator)
- Bad performances until 100s: worse than OCXO

OCXO locked to high stability USO

- Largest SWaP (in line with REQs considering margins)
- Possible alternative to miniRAFS in terms of performance

OCXO locked to mini-USO

- Performances better than/comparable with USO
- Very low SWaP w.r.t. both USO and miniRAFS

OCXO locked to miniRAFS (baseline technology)

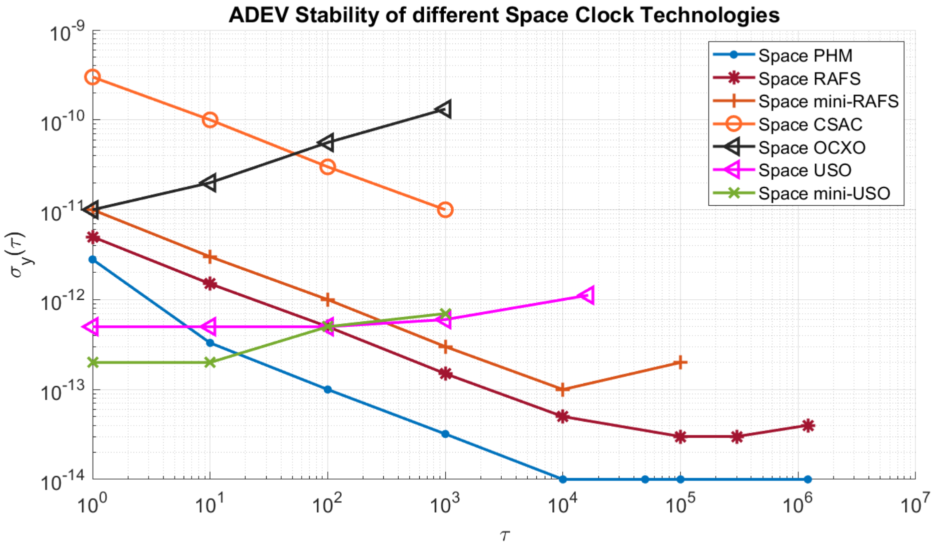
- Best SWaP – Performance Compromise

OCXO locked to RAFS

- Large SWaP
- High Performance

OCXO locked to PHM

- Very Large SwaP
- Very High Performacne



Type	SWaP [m^{3}xkgxW]	ADEV @1000s	Refresh Time for Best Performance	SISE @1000s only due to ADEV @1000s
OCXO	6,76E-07	1E-10	1s	100ns
CSAC	8.15E-08	1E-11	1000s	10ns
mini-USO	0.51E-03	7E-13	100s	0.7ns
USO	21.7E-03	6E-13	100s	0.6ns
mini-RAFS	2.62E-03	2E-13	1000-10000s	0.2ns
RAFS	5.90E-02	1.5E-13	1000-10000s	0.2ns
PHM	3.56E+01	3.0e-14	1000-10000s	0.05ns

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NAVANT

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NAVANT S/S

/// NAVANT

- Objective: antenna design and development of EBB for MoonLight

/// Performed activities

- at design level
  - Selection of baseline NAVANT architecture
  - Antenna technology identification
  - Detailed design of NAVANT
- At test level
  - Realization of high representative EBB
  - RF testing covering all the RF performance requirements

/// Outcomes

- EBB validate the design through testing (RF). Performances met the specification.

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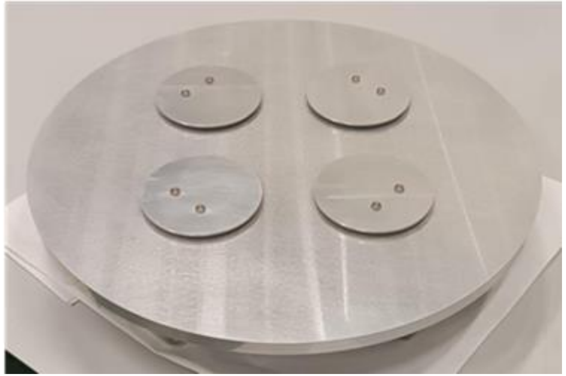
NAVANT S/S

- /// NAVANT description
- /// Selected baseline NAVANT (NAVigation ANTenna) is a flat phase array made of 4 patch AL radiators, placed on a circular rim ground plane acting also as structural panel. On the same panel, in the back side, there is the fully integrated beam former realised in square coaxial technology. The overall unit results in a quite compact solution.



Front view (2x2 array)

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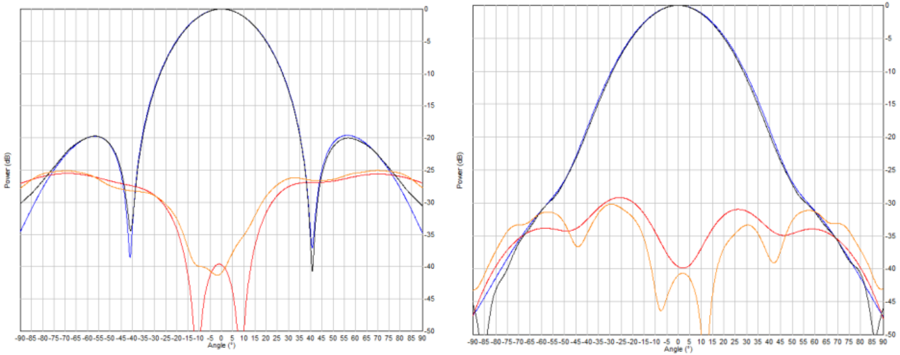
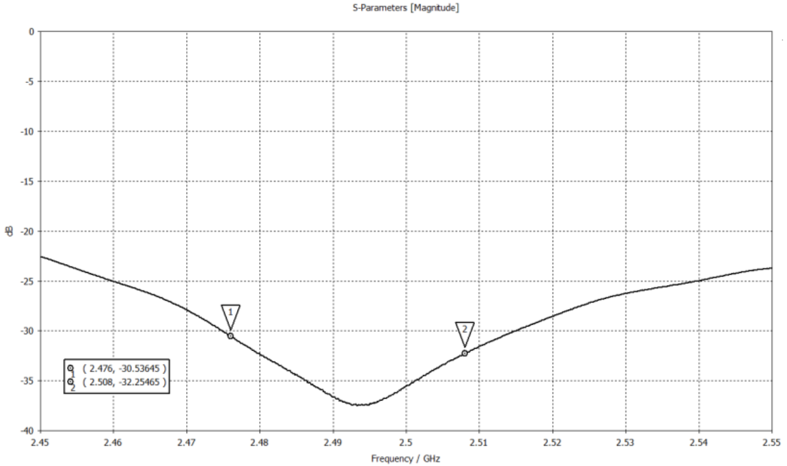
NAVANT S/S

/// NAVANT main perfoamces

/// Both radiated (gain, AR, CoP,..) and conducted (RL) performances met the specification



Predicted vs measured main cut (Typical)



Measured RL

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THALES ALENIA SPACE OPEN

SGU

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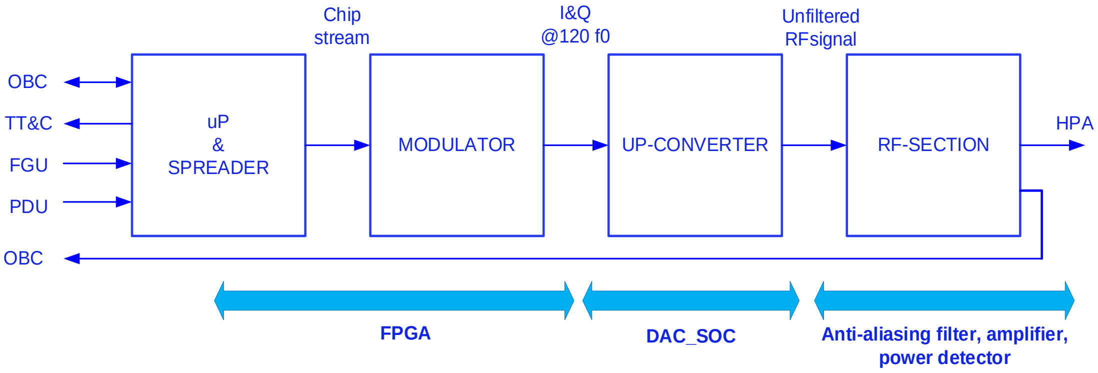
SGU S/S

/// Key Objectives and Main Achievements

- to explore and trade-off the needs of Lunar on-board navigation signal generation
- to embed flexibility, to track the evolutions of Lunanet and keep interoperability

identifying fear evens: effects, source, detection



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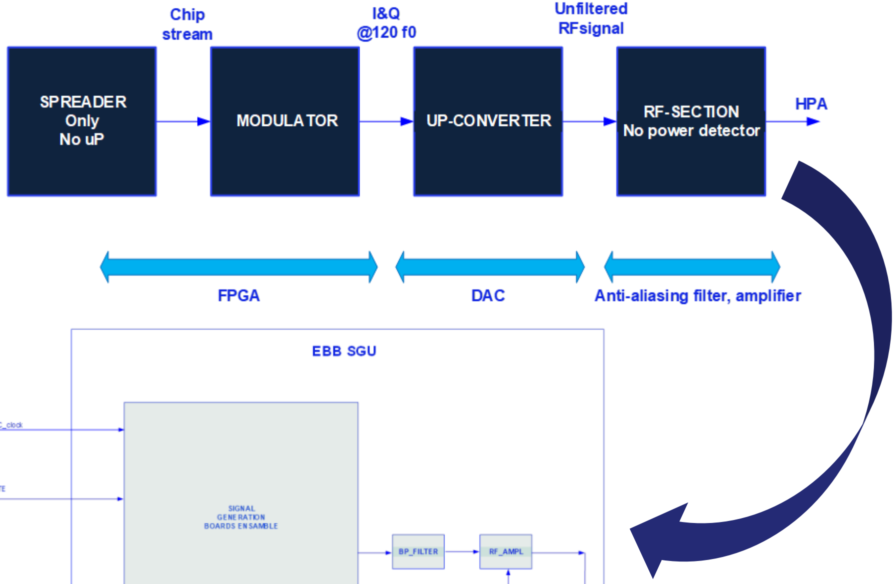
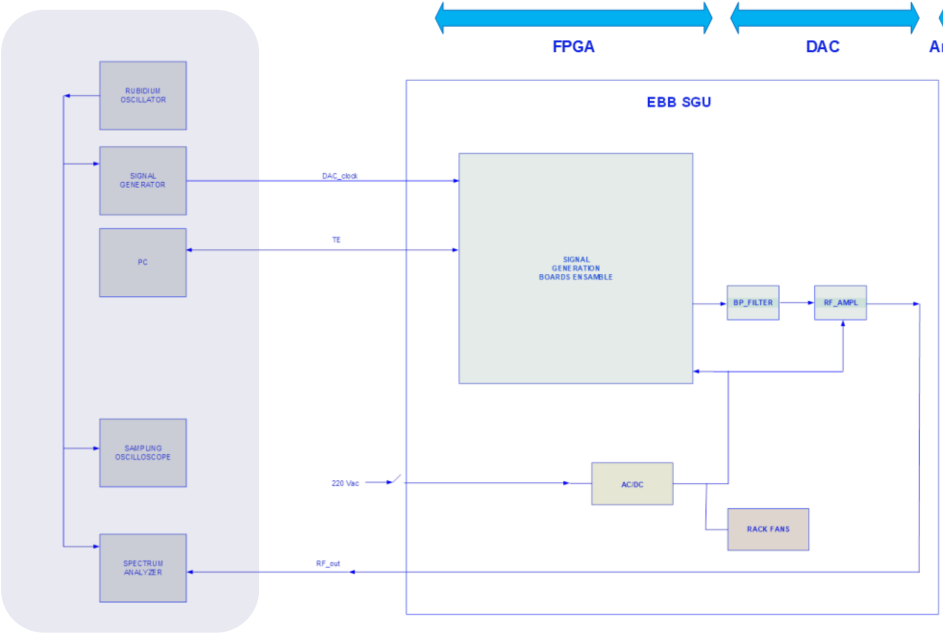
SGU S/S

/// EBB SGU

- Focusing what to verify experimentally
- Design the EBB





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EBB SGU – DRY RUN & TEST CAMPAIGN

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EBB INTEGRATION AND TESTING

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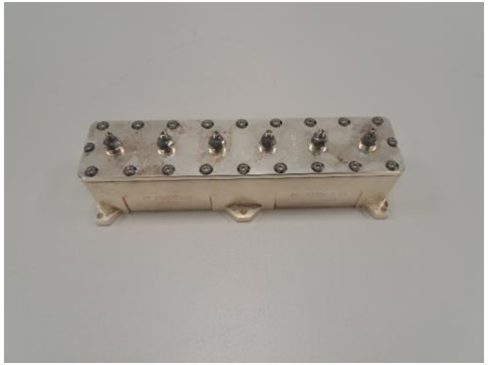
EBB INTEGRATION AND TESTING

/// RF tests on SGU and payload (SGU + RF frontend)

Signal Generation Unit (SGU)



RF frontend: Power Amplifier and Bandpass Filter

/// Integration of elements, with support equipment

/// Preliminary tests, power tests

/// (Spurious) emission tests

/// Quality of signal, phase noise

/// Timing tests

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TEST RESULTS

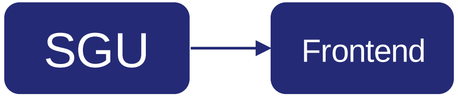
/// SGU: TPZ-B conducted the test campaign

All the tests have passed with the following exceptions/remarks:

- 1 NC found on Spurious test
  - Non-compliant spur found at clock frequency, which was solved at payload level with cavity (band-pass) filter
- Phase noise test not completely representative with current test-setup
  - Inconclusive for deviations < 1 kHz, due to elevated phase noise of external signal generator. In FM, signal generator will be integrated in system.
  - Remaining deviations passed.
- One of the test has not an associated Pass/Fail Criteria since it has to be intended as a measurement and not as a requirement verification test

/// Payload: TPZ-B conducted the test campaign

- All the tests have passed



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VLBI

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VLBI TRANSMITTER ON THE MOON: KEY OBJECTIVES

/// Identification and definition of user requirements from scientific objectives for lunar VLBI

/// Definition of the instrument technical specifications in line with the user requirements and compatible with lunar lander platform

- Technical specification and preliminary statement of compliance
- Electrical ICD and IRD

/// The instrument preliminary design

- Electronic box design
- Antenna design
- Development, verification, and validation plan

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VLBI TRANSMITTER ON THE MOON: MAIN ACHIEVEMENTS

/// Derivation of objectives and specifications for the Lunar VLBI:

- Scientific objectives identified and defined
- User requirements derived
- Technical specifications derived
- Interface requirements and specifications defined

/// Definition of the preliminary design of the Lunar VLBI Transmitter

- Heritage baseline specified
- Delta development points identified
- Antenna subsystem development efforts assessed and investigated

/// Preliminary development plan

- Estimated efforts and actions needed for practical development of the lunar VLBI Transmitter

/// A preliminary assessment of the operational aspects

- Modeling of the VLBI Transmitter based on AWS-proposes specifications
- Modelling of the VLBI Transmitter in collocation with other space-geodetic techniques (i.e., laser ranging)

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VLBI TRANSMITTER ON THE MOON: PRELIMINARY DESIGN PRESENTATION

/// Space-geodetic instrument

- Electronic box
- Antenna

/// Multichannel and wideband

- S band (3.1 – 3.3 GHz)
- C band (5.25 – 5.41 GHz)
- X band (8.2 [or 8.025] – 8.4 GHz and 9.3 – 9.8 GHz)

/// VGOS compatible

- 2-14 GHz
- 0.1 – 10 Jy

/// Multiple waveforms supported

- Wideband white noise (conventional VLBI observations)
- Spread spectrum (time transfer / single-station ranging)

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VLBI TRANSMITTER ON THE MOON: PRELIMINARY ARCHITECTURE

/// Electronic box:

- Power supply PBA (28 V DC, unregulated, to various DC regulated values)
  - new development (GENESIS VLBI Transmitter project is based on 5V DC regulated power supply interface)
- Digital PBA (signal generation, interface host, MCU, FPGA, clock distribution network, etc.)
  - baseline based on GENESIS VLBI Transmitter project, minor or no delta-redesign
- RF PBA (RF amplification and filtering)
  - derived from GENESIS VLBI Transmitter project, major delta-redesign: updated amplification stage of RF front-end to compensate for long distance (GENESIS is 6000 km, while Moon is ~400000 km)

/// SW/FW architecture

- SW on bare metal
- FW-based signal generation and signal processing
- TMTC interface based on PUS/UART/RS-422

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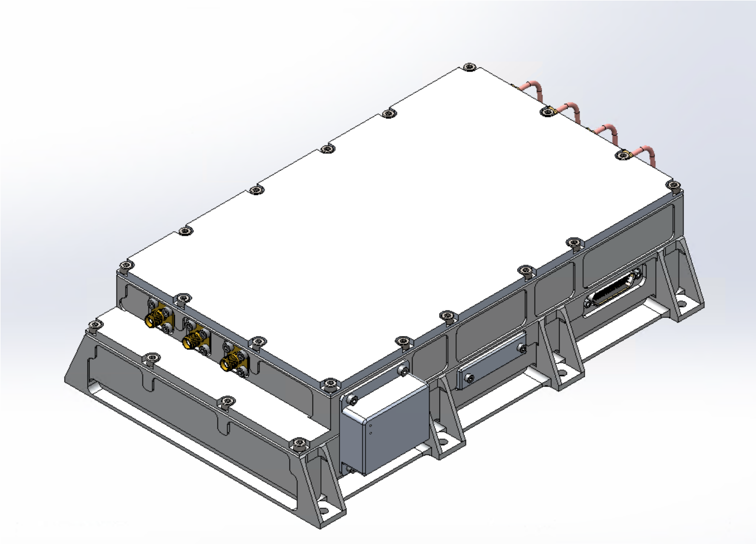
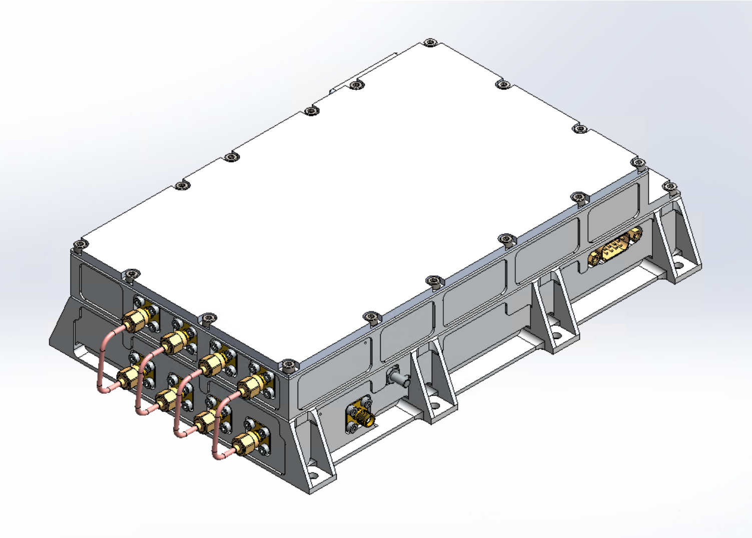
VLBI TRANSMITTER ON THE MOON: PRELIMINARY RENDERING

/// E-box drawings based on GENESIS VLBI Transmitter





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LRR

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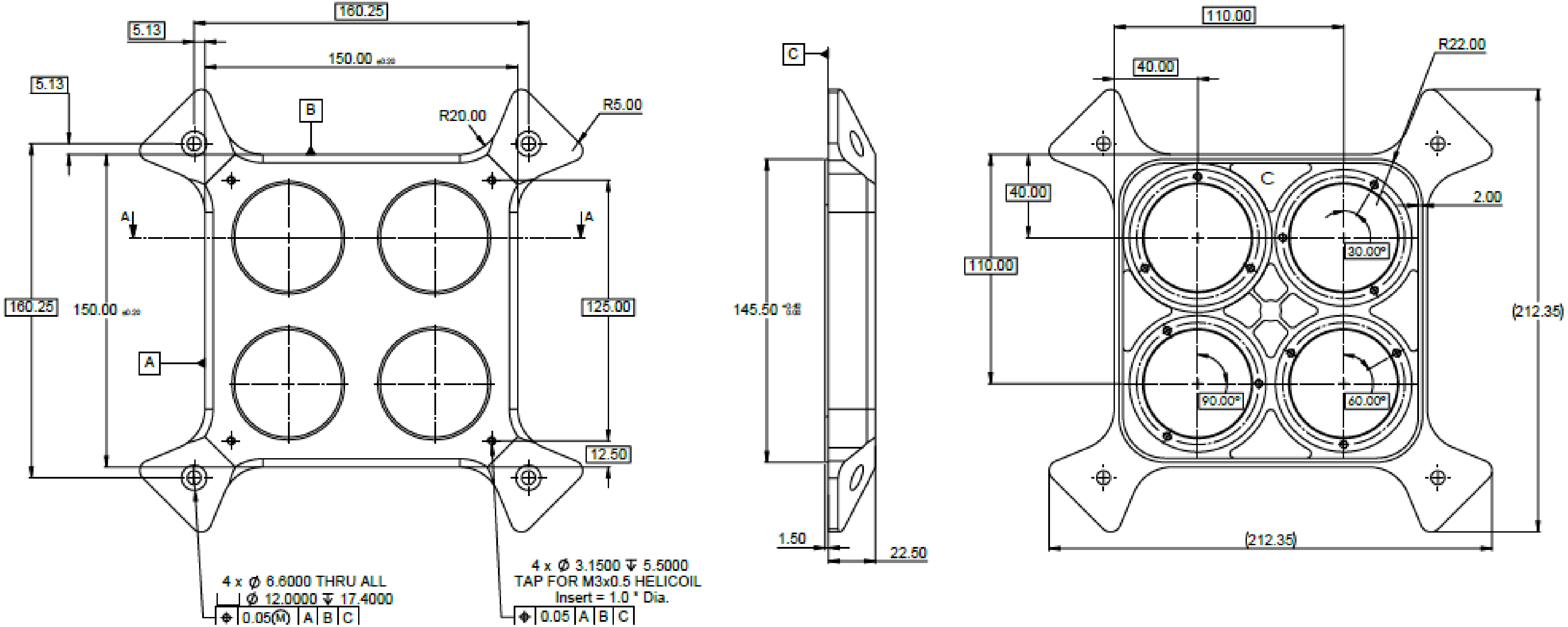
LRR EBB, MECHANICAL DRAWING (FRAME)



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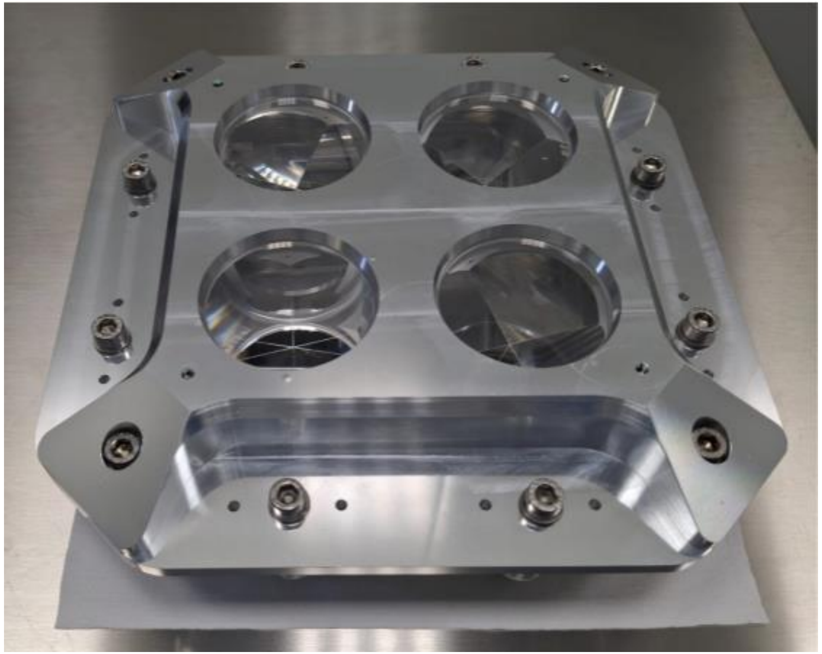

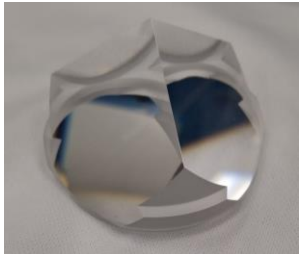

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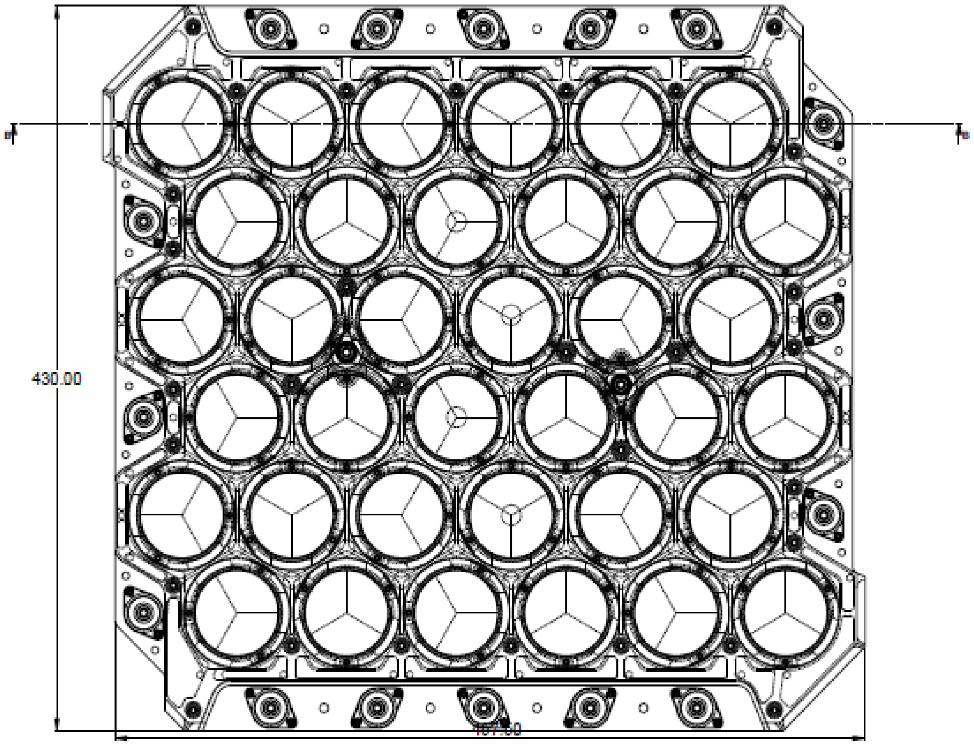

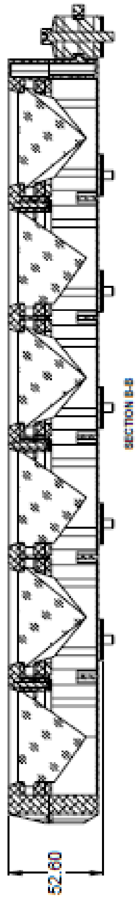

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LRR: KEY OBJECTIVES AND MAIN ACHIEVEMENTS

- Done:
- EBB HW drawings
- EBB HW procurement
- CCR Optical Tests and Analysis
- EBB Assembly
- EBB Mechanical tests (random vibes)
- EM LRR HW Drawings (in progress, under ASI, outside this NAVISP contract)

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LRR: CONTINUATION AFTER NAVISP

/// To Be Done:

/// EM LRR HW procurement (CCRs and Frame)

/// CCR Optical Tests and Analysis

/// EM LRR Assembly

/// EM LRR Mechanical tests

/// EM LRR TVT

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WRAP-UP

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MAIN PROJECT OUTCOMES AT PAYLOAD LEVEL

- This activity realized a demonstrator that helped to demonstrate the compliance with the requirements.
- Thanks to the demonstrator it will be possible to assess the performance at payload level considering different KPI including both QoS and RF domains.
- In the framework of this activity it has been also verified the compliance to the updated version of LNIS requirements (emerged when the design and development was in advanced stage).
- This demonstrator provides a de-risk for the design and development of future navigation payload for lunar mission.
- In addition to that, this demonstrator can contribute to other initiatives beyond lunar applications (e.g. Mars).

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