In-Orbit Demonstration of the iSIM-170 Optical Payload Onboard the ISS

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ABSTRACT

iSIM-170 is an optical payload for Earth Observations with sub-meter resolution in VNIR bands. The payload will be in-orbit-demonstrated at the ISS after a successful launch with the HTV-9 mission by JAXA and after its installation on the Kibo module occurred on June 11th, 2020. Prior to its flight, iSIM-170 underwent an accelerated development programme culminating in the successful completion of all verifications and reviews.

iSIM-170 has been developed by the Spanish company SATLANTIS, in collaboration with the University of Florida, to become the gold standard of imaging payloads for microsatellites. It consists of four integrated components: a binocular diffraction-limited set of telescopes; a high precision, robust and light alloy structure; a set of CMOS array detector units; and a high-performance-reconfigurable on-board image processor.

The goal of this in-orbit-demonstration mission consists of commissioning the payload and characterizing the overall instrument's capabilities, especially its ability to provide a factor ~2-3 improvement on spatial resolution below its diffraction limit design, using our super-resolution algorithms. The payload will be operated for three months to obtain TRL-8 qualification performing uplink and downlink activities managed by JAXA, as intermediary between iSIM-170 and SATLANTIS. Preliminary results demonstrating iSIM image quality will be shown at this conference.

THE FLIGHT MODEL OF THE INTEGRATED STANDARD IMAGER FOR MICROSATELLITES

The Flight Model (FM) of the "integrated Standard Imager for Microsatellites" (iSIM-170) is a version of the iSIM technology hosting a 170mm diameter primary mirror which will be used during the In-Orbit Demonstration (IOD) at the International Space Station (ISS). It is therefore a fully functional model with qualified parts, materials and processes that have been subjected to acceptance-level testing.

The IOD service provider has made the "IVA-Replaceable Small Exposed Experiment Platform" (i-SEEP) available for this demonstration. i-SEEP is a hardware adapter at the Exposed Facility of the Japanese module Kibo of the ISS (see Figure 1).

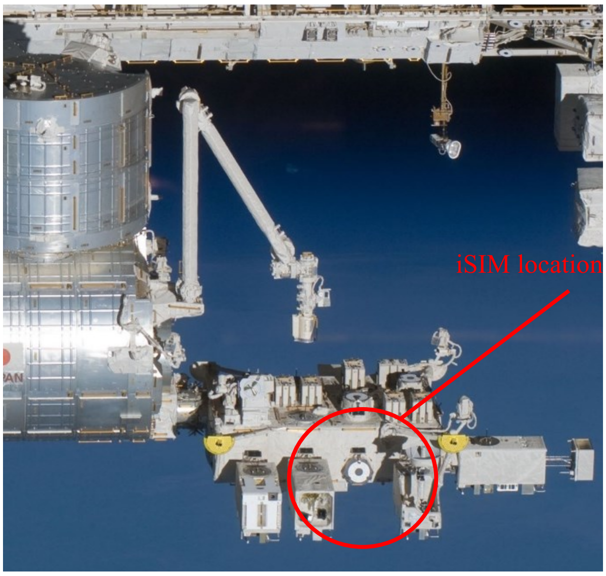

Figure 0: Location of iSIM-170 at the Exposed Facility of the Japanese module Kibo at the ISS.

Overview of Physical Architecture

The iSIM payload is roughly divided in two subsystems: the optomechanical subsystem and the electronics and control subsystem (ECS). The optomechanical subsystem is divided into two identical optical channels, supported by two structural plates.

As for electronics, image detectors are located at the end of each optical channel. One single electronic box accommodates the main HW of the ECS in charge of payload operations.

Figure 2 shows the fully integrated FM attached to the interface platform inside the SATLANTIS clean room. Below the opto-mechanical structure is the electronic box hosting all the PCBs of the ECS.

iSIM-170 FM Status

The assembly, integration, and alignment of the iSIM-170 FM was completed in Fall 2019. A series of fundamental functional tests were performed in-house to ensure the optical quality and that the optomechanical and electronics subsystems had been correctly integrated. Subsequently, the FM travelled to the facilities of Alter Technology TÜV Nord (Madrid), where it was subjected to acceptance level testing. These tests included vibrational tests, thermal testing (both vacuum and thermal cycling) and Electro Magnetic Compatibility (EMC) testing. The outcome of the testing campaign was very positive, and the FM successfully passed the qualification testing campaign.

The iSIM-170 FM arrived in Tsukuba (Japan) in December 2019, where it passed the final acceptance review by JAXA. In May 20th, 2020, iSIM-170 was launched on board the JAXA HTV-9 mission and arrived at the ISS in May 25th. iSIM-170 was successfully installed on to the i-SEEP platform and transferred to the Exposed Facility of the Kibo module on June 11th, 2020, starting its nominal operations afterwards.

The payload will be in operation for three months in order to obtain TRL-8 qualification in space environment. The operations are foreseen to start approximately two weeks after the payload installation on the i-SEEP platform. In the following Sections, we describe the iSIM-170 payload in detail as well as the planned operations at the ISS.

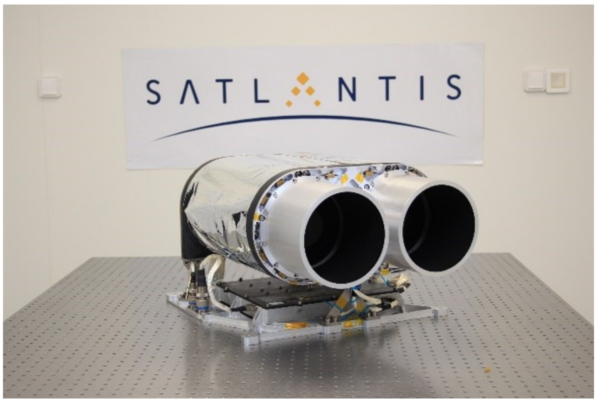

Figure 2: The Flight Model of the iSIM-170 payload. The electronic box is located directly below the opto-mechanical system (the base structure shown here is the mechanical interface plate with i-SEEP).

iSIM-170 FM OPTICS

The iSIM payload consists of two identical optical channels. The layout of each optical channel corresponds to a modified Maksutov-Cassegrain design, that provides diffraction-limited image quality for wavelengths between 450 nm and 1000 nm across the entire field-of-view (FOV).

The design consists of three optical elements: a primary mirror (M1), a corrector lens (M2) and a field lens (FL). All surfaces are spherical. Both M1 and M2 make use of the “Mangin mirror” concept, which allows saving in number of optical elements, at the cost of increasing sensibility and reduced tolerances.

Figure 3 shows the optical design of one optical channel, where the collimated light enters the system from the left, and finally forms an image in the focal plane, located right after the FL.

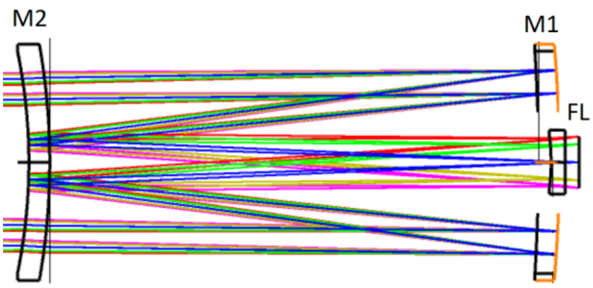

Figure 3: iSIM optical design and ray path.

Each optical channel has a focal length of 1500 mm, an entrance pupil diameter of 150 mm, and a FOV of 1º (although the detector limits the FOV to 0.86º x 0.65º).

Mirror coatings and baffles are used in order to capture the maximum number of usable photons, while rejecting those that could reach the detector with stray trajectories.

Figure 4: M1 (top left), FL (bottom left) and M2 (right) for iSIM-170. Note they are not to scale.

iSIM-170 FM OPTO-MECHANICS

The main purposes of the mechanical structure are two-fold: (i) to hold the optical elements and the detector within a compact, lightweight, thermally stable system; and (ii) to ensure the attachment of the full iSIM system to the satellite platform and ensure the survival of iSIM to the launch and mission environments.

The structure is composed of two plates (rear and front) coupled by 14 struts and connected to the satellite surface by 3 blades in an isostatic configuration. The plates hold the optical elements with the use of cells, the detectors, and have 3 pairs of baffles to reduce stray light.

This structure combines materials with low density, high strength and appropriate thermal expansion coefficients in a design that ensures thermal stability, i.e, a constant distance between the optical elements and the detector that fulfils the required optical parameters. Moreover, all mechanical structure elements are coated with PNC black paint to reduce stray light and protect the system from radiation.

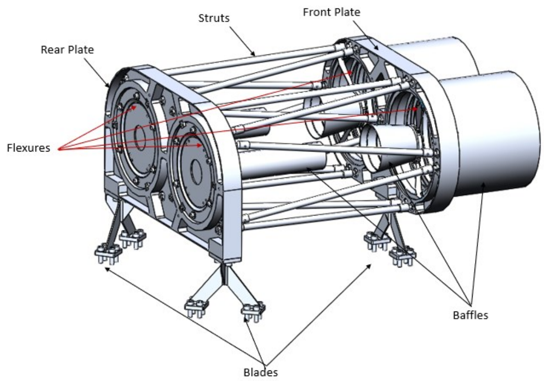

Figure 5: Sketch of iSIM mechanical structure.

The Rear and Front Plates constitute the supporting elements where the remainder parts of the mechanical structure and optical elements are attached.

The Front Plate is an aluminium structure, lightweight and optimised to support the Fore Baffles on the front side, the Secondary Baffles and one end of the CFRP Struts on the rear side, and the Fore Blade at the bottom. In addition, the Corrector Lenses (M2) are held inside this plate by means of cells.

The Rear Plate is an aluminium structure, lightweight and optimised to support the Primary Baffles and one end of the CFRP struts on the front side; the detector and the Field Lenses (FL) on the rear side, and the Rear Blades at the bottom. In addition, the Primary Mirrors (M1) are held inside this plate by means of the cells.

Fourteen struts join the Front and Rear Plates and provide the stiffness which limits lenses decentre and defocus caused by potential mechanical deflections. Each CFRP strut is made of a CFRP rod that provides stiffness with one titanium fitting in each end to obtain the correct attachment with the plates.

The joints between rods and fittings have been carried out with space-qualified adhesive. To reinforce the attachment between the fittings and the rod, a stainless-steel pin has been added to each fitting. Considering the plate dimensions and the CTEs of the involved materials, the struts ensure the relative positions of the optical elements.

The optical elements M1 and M2 are mounted within the cells in a three-point configuration where an adhesive is radially inserted, preventing axial and radial displacement of the lenses. The cells also incorporate an O-ring between surfaces which ensures that the interface between the cells and the Front & Rear Plates is radially athermal.

Fore, Primary and Secondary Baffles have been designed with vanes in the inside surfaces, to reduce stray light along the optical path. The Fore Baffles provide shade to the M2 lenses from sunlight and other stray light paths. The Primary and Secondary Baffles are designed to block stray light resulting from unwanted reflections in the internal surfaces of M1 and M2.

Finally, three titanium blades have been designed as the mechanical interface between the satellite platform and the payload in an isostatic configuration. Each blade is attached to the payload structure with four screws and to the satellite platform with eight screws.

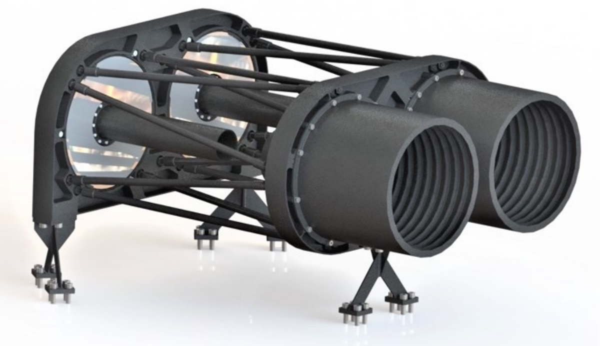

Figure 6: iSIM-170 opto-mechanical structure fully assembled.

iSIM-170 FM ELECTRONICS AND CONTROL SUB-SYSTEMS (ECS)

One of the main objectives of iSIM-170 FM is to demonstrate the accomplishment of the fully developed ECS, both HW and SW. In particular, we would like to test: (i) the suitable integration of a third-party COTS Camera; (ii) the design of the control application architecture, ensuring that quality attributes, such as usability, performance, reliability, and security, are covered; (iii) the implementation of the final SW version, including all functionalities for the IOD; and (iv) and the verification of all previously described objectives.

The following sections describe the HW and SW of the ECS' FM.

ECS Hardware

The main HW actors of the ECS' FM are the following:

COTS Camera: in charge of image acquisition and the subsequent transmission of the images to the SmartCIA for storage.

SmartCIA: the core of the iSIM ECS. It is a single PCB that hosts the main control of the iSIM ECS and communicates with the COTS Camera and the i-SEEP demonstration platform.

Power interface module developed to galvanically isolate the electrical systems of iSIM and i-SEEP, as required for the ISS.

Figure 7 shows the high-level architecture of the ECS's iSIM-170 FM.

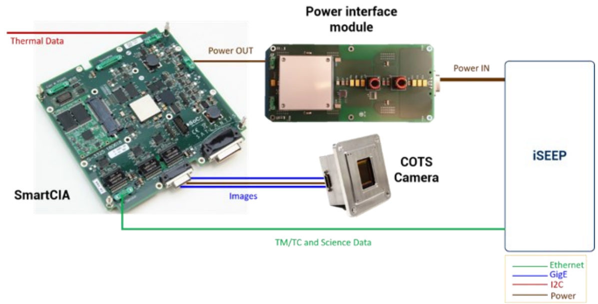

Figure 7: ECS's HW high-level architecture.

COTS Camera

The selected COTS Camera is a Sentech STC-CMB120APCL, a monochrome camera with a CMOSIS CMV12000 sensor. This sensor is a 2D array of 4096 x 3072 pixels each with a size of 5.5 µm. The COTS Camera is powered through the SmartCIA with 12V.

Figure 8 shows the front and back view of the selected COTS camera.

Figure 8: Sentech STC-CMB120APCL camera.

The COTS camera has been adapted as follows. First, the camera HW has been rearranged to fit into a custom case designed to protect the camera HW and fix it to the mechanical structure. Second, the COTS camera connector has been modified to provide a robust space-grade interface (see Figure 9).

Figure 9: The Sentech COTS Camera assembled with the new case and interface.

In addition, epoxy and conformal coating have been applied to the camera's PCBs: epoxy to the critical components to guarantee survival to launch vibrations, and conformal coating to protect it against moisture, dust, chemicals, and temperature extremes. While thermal grease has been used in several contact points to allow for heat dissipation.

The SmartCIA

The SmartCIA's board has been designed to fulfil the functions of a processor and a communications interface between the ECS and the platform. Figure 10 shows a photograph of the manufactured SmartCIA in SATLANTIS' laboratory.

The board's core is a SoC based on a FPGA that uses a secondary MCU as a Supervisor. The MCU Supervisor has three main functions:

- Load the OS into the SoC during the start up.
- Oversee the operation of the SmartCIA and the SoC.
- Restart the SoC in the event of an emergency.

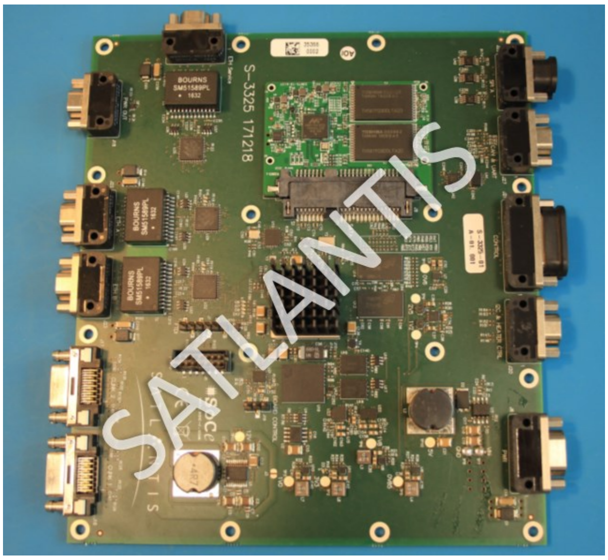

Figure 10: SmartCIA at the SATLANTIS laboratory

The SmartCIA uses four different types of memories:

- Two flash memories to store the OS.
- Two RAM memories.
- An SSD to store the images.
- An eMMC to storage any other type of data.

The HW of the iSIM-170 FM ECS also includes all required interfaces to power, connect and communicate the different actors. The main interfaces developed are:

GigE: ethernet is used to check the status and to monitor the SmartCIA.

Dual GigE Vision: used for communications between the SmartCIA and the COTS Camera. This interface is used for transmitting commands, images and the monitorisation information from the COTS Camera to the SmartCIA. The use of a Dual GigE interface allows to double the number of images that can be transmitted.

UART: used for communications between the SmartCIA's SoC and the MCU Supervisor. The SoC uses this interface to send commands to the MCU Supervisor and to receive information about the status of the SmartCIA.

I2C: used to transmit thermal data to the SmartCIA's SoC.

CAN: used for TM/TC and the transmission of additional data, such as GPS data, between the

SmartCIA and the platform. Two CAN channels are used for redundancy and to increase safety.

UART (using the RS-422 technical standard): two UART channels are used for the same purpose as CAN. Depending on the requirements of the platform, it is possible to use either CAN, UART or both.

SpaceWire: used for the transmission of Science Data, that is, images plus metadata.

For the In-Orbit Demonstration, the iSIM-170 FM will only use the GigE interface to communicate with i-SEEP, according to the communications available. This interface is used for all communications between i-SEEP and the SmartCIA, substituting the CAN, UART and SpaceWire interfaces.

Power Interface Module

Regarding the power, a power interface module has been developed to galvanically isolate the electrical systems of iSIM and i-SEEP, as required for the ISS. This isolated power interface module consists of a PCB designed to interface the i-SEEP power system with the iSIM electronics and act as an electromagnetic interference (EMI) filter (see Figure 11).

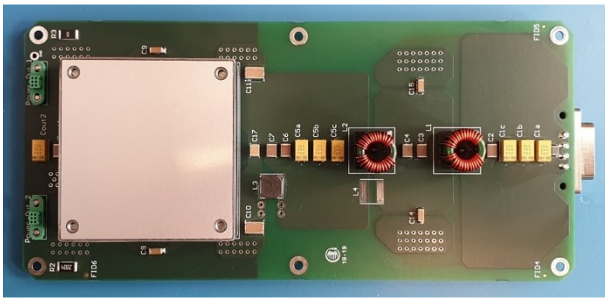

Figure 11: Power interface module.

It has an operative input voltage range from +18V up to +36V, thus respecting the power out requirements of the i-SEEP system (range: from +26V up to +30V). The power interface module output voltage is +24V with a maximum deliverable power of 100W and an efficiency up to 92%.

The Electronic Box

The objective of the electronic box is to protect the PCBs from radiation and to evacuate the heat dissipated by the electronic components.

The original electronic boxes have been redesigned in order to optimise the attachment to the i-SEEP platform. As opposed to the iSIM QM where each PCB belonged to a separate box, the FM features one single electronic box that houses the three main electronic components (two Smart CIAs and one Power Module).

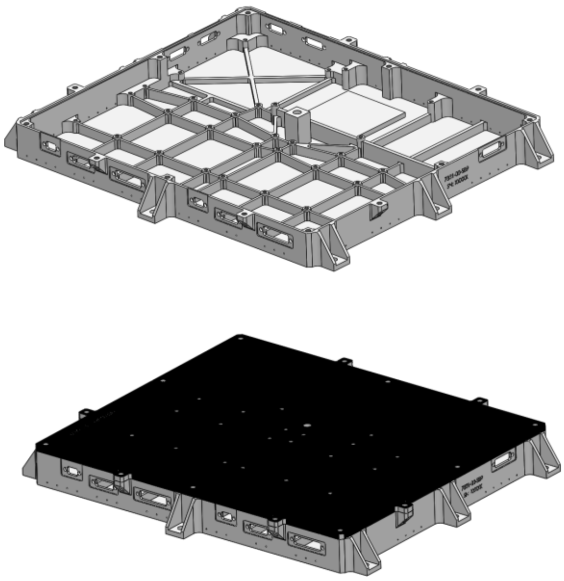

Figure 12: Electronic box without cover plate (top) and with cover plate (bottom).

The iSIM-170 FM electronic box is composed of a baseplate and a cover plate (see Figure 12). The SmartCIAs and the Power Module are attached to the baseplate. To evacuate the heat dissipated by the electronic components, the external surfaces of the electronic box are black anodized as shown in the figure above.

ECS Software

The SW of the iSIM-170 FM ECS is a set of codes that control the whole ECS and runs in embedded environment. It is divided into three blocks, depending on the HW each block is executed on (see Figure 13): the COTS Camera SW; the MCU Supervisor SW; and the SoC SW.

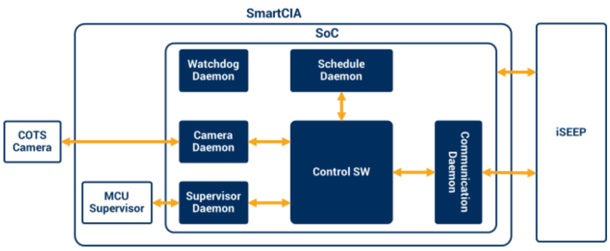

Figure 13: High-level architecture of the ECS SW.

The COTS Camera SW is a commercial SW provided by the manufacturer. The MCU Supervisor and the SoC SWs are executed in the SmartCIA. The MCU

Supervisor SW controls its respective HW and works as a slave of the SoC SW.

The SoC SW contains the ECS Control SW and 5 Daemons. The ECS Control SW is the main SW and controls the execution of other SWs and peripherals (the COTS Camera and the MCU Supervisor).

The ECS Control SW has been modified to account for the impact of the established communication interface with i-SEEP, on the SmartCIA's operation mode (e.g. it is not possible to maintain constant communication with the Ground Station).

The Daemons are five programs that run in the background as slaves of the Control SW. The Daemons unburden the Control SW and allow a greater flexibility and safety.

Three further daemons have been developed for the iSIM-170 FM: Communication Daemon, Schedule Daemon and Watchdog Daemon. Additionally, new protocols have been implemented for the transfer of files following the specifications from the Interface Control Document.

Camera Daemon: controls the communications with the COTS Camera and manages the reception and storage of the acquired images.

Supervisor Daemon: handles the communications with the MCU Supervisor.

Communication Daemon: manages all communications between the Control SW and i-SEEP, except for the Science Data and file transmission, reducing the overload of the Control SW. These communications include Telecommands, Telemetry and the synchronization of the timestamp. Telecommands and timestamp synchronization are performed over TCP/IP, and telemetry is done over UDP. This Daemon includes several strategies for the recovery of the communications in case some fault occurs.

Schedule Daemon: During the IOD it will not be possible to keep constant communication between iSIM and the Ground Station. Therefore, several schedule files will be uploaded into the SmartCIA to program operations in advance. The Schedule Daemon manages and analyses these schedule files to determine what to do in each moment. If a new action is required, it transmits this command to the Control SW, which ensures that the action is executed correctly. A total of 21 schedule files will be uploaded on iSIM during the 91-day mission.

Watchdog Daemon: Oversees the execution of the ECS SW. It verifies that the SmartCIA is working properly and can restart any program if it detects that it is not operating correctly.

According to the specifications of the IOD, two protocols have been implemented for the transfer of files between the SmartCIA and i-SEEP:

SFTP is used for the uplink of files from i-SEEP to the SmartCIA. These files include schedule files for the Schedule Daemon and other update files.

FTP is used for the downlink of files from the SmartCIA to i-SEEP. These files include images acquired by iSIM and data logged.

In normal operation, the SoC SW is executed over an embedded Linux OS. A secondary and lighter PetaLinux OS can also be loaded into the SoC. The PetaLinux OS takes control of the SoC in the event of an emergency which might impede normal operation, preventing the loss of control of the ECS.

The following subsections focus on the description of the iSIM ECS Control SW and the Interface Simulator SW developed to simulate and test the communications between iSIM and i-SEEP.

iSIM ECS Control Software

The ECS Control SW is divided into five independent subsystems (see Figure 14):

*Configuration***:** Initialisation and configuration functions for the communication interfaces and logging.

HW Info: Acquisition of information from the HW. This includes execution time, SoC temperature, resource usage, etc.

Inputs Driver: This module allows the reception of data, including Telecommands sent by the i-SEEP, the status data and images sent by the COTS Camera, the MCU Supervisor data and the Thermal Data.

SmartCIA Control SW: The Control SW manages the SmartCIA, the COTS Camera and the MCU Supervisor. Its main functions are to control communications, host the Control Logic and manage the data storage.

Outputs Driver: This module allows to send data through different communication interfaces. This data includes the Monitoring Data and the Science Data sent to i-SEEP, and the commands sent to the COTS Camera and the MCU Supervisor.

The SmartCIA Control SW is further divided into several subsystems, including: Inputs Adaptation, Internal Memory Generation, Control Core, Diagnosis Subsystems, and Outputs Adaptations.

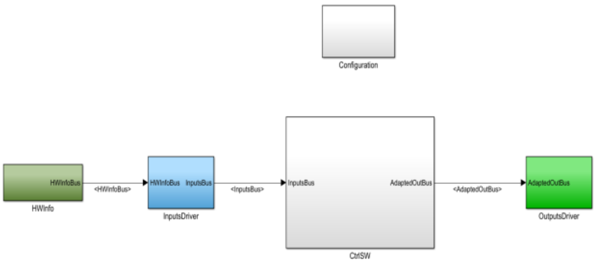

Figure 14: High level architecture of the Smart-CIA's Control SW.

Interface Simulator SW

The Interface Simulator SW has been developed to simulate and test the communications between iSIM and i-SEEP, the demonstration platform. The Interface Simulator SW has the following functionalities:

- receive, interpret and log the Telemetry sent by both SmartCIAs;
- transmit Telecommands to both SmartCIAs;
- host the server for the Time Synchronization of the SmartCIAs.

Finally, the transfer of files through FTP and SFTP is tested using commercial SW.

Figure 15 shows a snapshot of the Interface Simulator SW during testing.

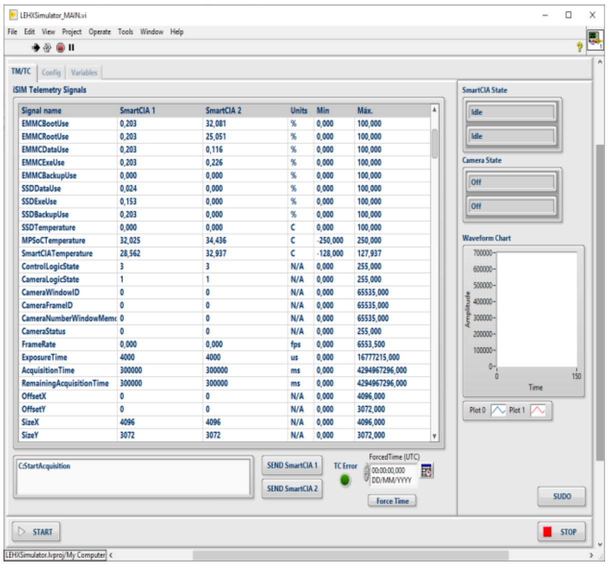

Figure 15: Interface Simulator SW.

iSIM-170 FM INTERFACES

Payload Coordinate System

The payload coordinate system is shown in Figure 16 where the Z axis corresponds to the optical axis.

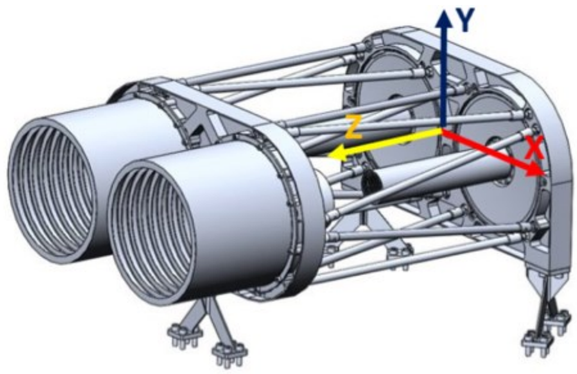

Figure 16: Payload local coordinate system.

Given that the iSIM payload needs to take images of the Earth, the payload's Z axis must point at nadir (±30º) most of the time.

Envelope and Mass Budget

The iSIM-170 IOD FM has a volume of 476.80 x 595.00 x 345.50 mm^3 and a total mass of 16.637kg. Figure 17 indicates the dimensions of the envelope.

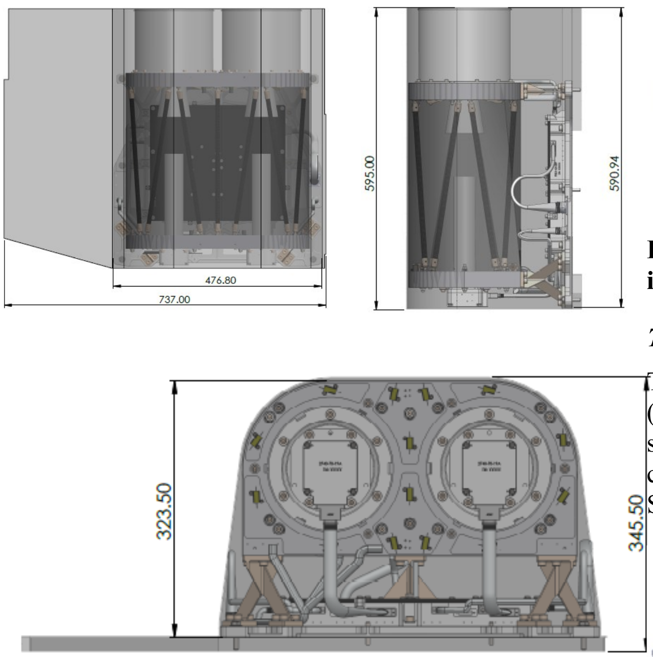

Figure 17: iSIM FM envelope.

Mechanical Interfaces

For the IOD a specific interface structure has been designed and manufactured to provide the mechanical interface between iSIM-170 FM and i-SEEP (see Figure 18). It is designed to securely mount iSIM and the electronic box, as well as to provide a mounting point for the external harness during launch. Note that an electronic box has been designed to host all PCBs of the ECS.

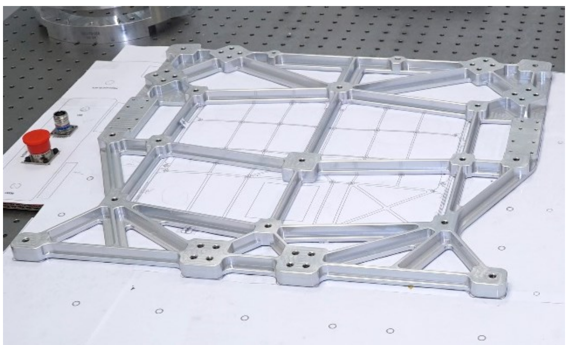

Figure 18: iSIM/i-SEEP mechanical interface plate.

The three titanium blades of iSIM-170 are attached to the interface plate. The blades are circumscribed, creating a three-point isostatic interface (see Figure 20).

Figure 20: iSIM-170 FM mounted on the mechanical interface with i-SEEP.

Thermal Interfaces

The thermal interface consists of two thermal covers: (1) an MLI cover that wraps around the mechanical structure, covering the optical channels, and (2) a beta cloth that covers the whole payload and connects to i-SEEP.

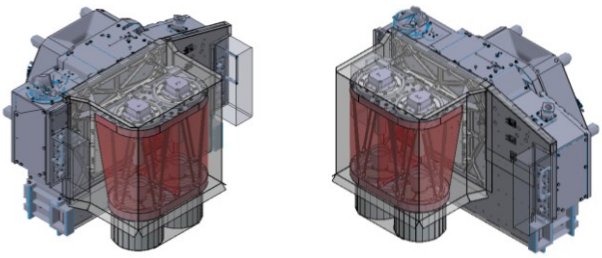

Figure 21: iSIM-170 FM mounted on the i-SEEP platform.

The MLI cover is indicated in red in Figures 21 and 22 and the beta cloth in grey. Note that an additional SLI cover is placed in between the two optical channels to reduce cross talk of light from one channel to the other.

The connection between iSIM-170, i-SEEP and the beta cloth is accomplished via the employment of hold down positions which are situated to match the predetermined Velcro positions on i-SEEP.

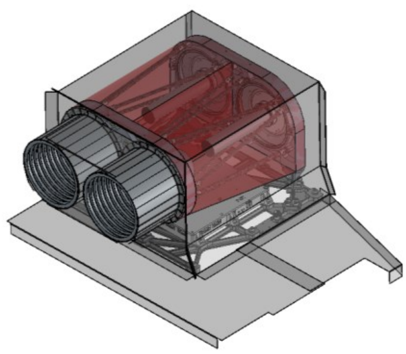

Figure 22: iSIM/i-SEEP secondary thermal interface (beta cloth).

Electrical and Communication Interfaces

The electrical and communication interfaces consist of an external power harness to connect to the 28V power interface located on i-SEEP, and a data harness to connect the SmartCIA with the ethernet interface of i-SEEP.

The harnesses combine aerospace grade wire and shielding with the required military-grade connectors.

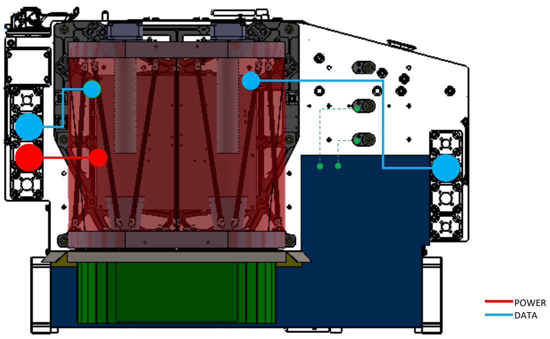

Figure 23: Electrical connections to i-SEEP.

GigE is used for the communication between the ECS and i-SEEP. Since i-SEEP uses Ethernet for all communications, the harness has been modified so that only Ethernet is used for all communications between the SmartCIA and i-SEEP, i.e. both TC/TM and Science Data are communicated through Ethernet (see Figure 23).

A high-level communications architecture diagram is displayed in Figure 24. The direction of the arrows indicates the path followed by the data. Note that SATLANTIS can only communicate with JAXA.

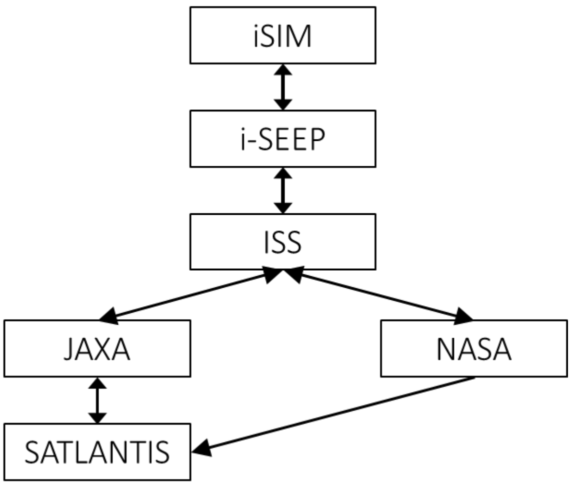

Figure 24: High-level communications diagram between iSIM and SATLANTIS.

Power Budget

The power budget has been estimated for three different scenarios: power off, stand by and acquisition. The following tables list the power budget for each scenario and each HW actor.

Table 1: Power budget for Power Off scenario.

Board	Voltage (V)	Current (A)	Power (W)
SmartPower	28	0	0
SmartCIA 1	24	0	0
SmartCIA 2	24	0	0
Camera 1	0	0	0
Camera 2	0	0	0

Table 2: Power budget for Stand By scenario.

Board	Voltage (V)	Current (A)	Power (W)
SmartPower	28	0.08642857	2.42
SmartCIA 1	24	0.22083333	5.3
SmartCIA 2	24	0.22083333	5.3
Camera 1	0	0	0
Camera 2	0	0	0
Total		**0.64930736**	**13.42**

Table 3: Power budget for Acquisition scenario.

Board	Voltage (V)	Current (A)	Power (W)
SmartPower	28	0.12492857	3.498
SmartCIA 1	24	0.22083333	5.3
SmartCIA 2	24	0.22083333	5.3
Camera 1	12	0.425	5.1
Camera 2	12	0.425	5.1
Total		**1.53780736**	**24.698**

SPECIFICATIONS

The following table summarises the specifications set for iSIM-170 FM, taking into account the panchromatic detectors and an average orbital height of 400km, consistent with the ISS orbit.

Table 4: iSIM-170 FM specifications for the IOD.

iSIM -170 FM IOD	
GSD (m) @400km	< 1
MTF at Nyquist	>30%
Swath (km) @400km	6
SNR (@0.3 albedo)	>100
Focal length (mm)	1500

FOV (rad)	0.015
Effective aperture (mm)	150
Payload mass (kg)	16.637
Payload volume (mm)	476.8 x 595.0 x 345.5
Power (W)	<50
Operational temp. range	+19.5ºC / +26.5ºC
Survival temp. range	-30ºC / +50ºC

DELIVERY OF iSIM-170 FM TO JAXA

The work on the iSIM-170 FM, in preparation for the IOD, started in January 2019 after two key milestones were achieved: the successful qualification to TRL-6 of the iSIM-170 QM, and the signature of the IOD contract with Space BD and JAXA. Less than one year later the iSIM-170 FM was successfully delivered to JAXA.

In order to secure this success, SATLANTIS worked together with Space BD and JAXA to define a schedule with strict milestones, including all activities of the preparation process up to the payload handover. These milestones are summarized as follows:

- July 2019: Interface tests in JAXA facilities to confirm design.
- September 2019: Phase 0/I/II for iSIM IOD officially approved.
- December 2019: Phase III for iSIM IOD officially approved.
- December 2019: Phase 3+ Interface tests in JAXA facilities to confirm built FM.
- December 2019: iSIM FM handed over to JAXA on the 18th of December.

This timeline is illustrated in the following two figures.

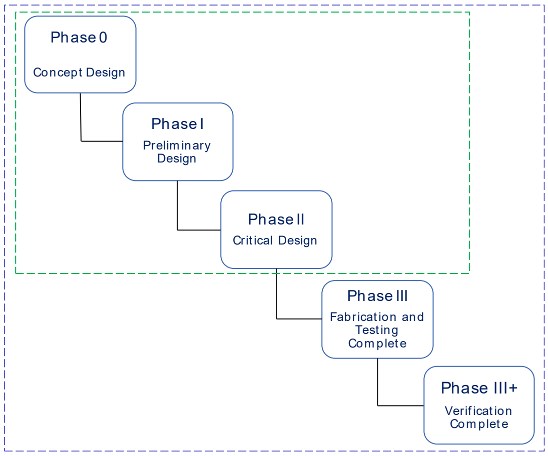

Figure 25: Flow chart of the steps followed during Phase 0/I/II and Phase III.

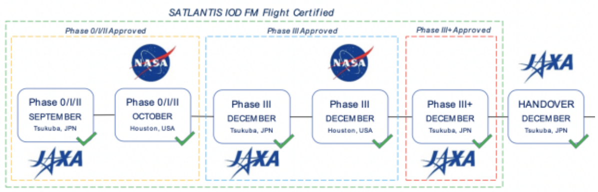

Figure 26: Timeline of achieved main milestones up to handover to JAXA in December 18th, 2019.

Between July and December 2019, the analyses and documentation for Phase 0/I/II and Phase III were carried out, revised, and completed. The following table summarizes the main key documents submitted to Space BD / JAXA during the SAR process. The complete set of documentation exceeded 5000 pages.

Table 5: List of key documents submitted to Space BD/JAXA for SAR Phases 0/I/II and III.

Doc ID	Rev	Document description	Ph
0010-7A-SB9	N/A	Envelope information (Drawing/CAD model) including MLI thickness, fastener & alignment pin IF, bonding points on I-SEEP	0/I/II
0010-7A-SB9	N/A	Design Drawing for iSIM	0/I/II
P001-PRO-T-001	9	iSIM Flight Safety Assessment Report for Phase 0/I/II	0/I/II
P001-PRO-T-002	3	Electrical Design & Analysis	0/I/II
P001-PRO-T-003	8	Structural Verification Plan	0/I/II

Doc ID	Rev	Document description	Ph
P001-PRO-T-004	9	Structure Analysis Report for iSIM	0/I/II
P001-PRO-T-005	4	Thermal Analysis Report	0/I/II
P001-PRO-T-006	6	Fracture Control Status Report	0/I/II
P001-PRO-T-007	10	Standard Hazard Report of iSIM	0/I/II
P001-PRO-T-008	6	Unique Hazard Report of iSIM Structure Failure of iSIM	0/I/II
P001-PRO-T-009	10	Unique Hazard Report of iSIM Shatter able Material Release	0/I/II
P001-PRO-T-010	5	Unique Hazard Report of iSIM EVA Sharp Edge	0/I/II
P001-PRO-T-011	6	Unique Hazard Report of Pinching/Entanglement due to Rotating Device	0/I/II
P001-PRO-T-012	9	Material Usage Identification List	0/I/II
P001-PRO-T-014	2	Software Specification (including Operation GSE)	0/I/II
P001-PRO-T-015	2	Operation scenario (including contingency plan)	0/I/II
P001-PRO-T-018	4	EVA Touch Temperature of integrated Standard Imager for Microsatellites (iSIM)	0/I/II
P001-PRO-T-019	3	OP-NOM Label Application	0/I/II
P001-PRO-T-020	4	iSIM-iSEEP GM Interface Test Plan	0/I/II
P001-PRO-T-021	5	iSIM-LEHX Interface Test Plan	0/I/II
P001-PRO-T-026	1	NASA HSMT - NUSIL CV9341	0/I/II
P001-PRO-T-028	4	iSIM OPERATIONAL CONTROL MATRIX (iSIM OCM)	0/I/II
P001-PRO-T-033	1	iSIM IOD - Verification Tracking Log	0/I/II
P001-PRO-T-035	3	iSIM IOD FM - Fore Baffle; ISS NCR EVA Sharp Edge	0/I/II

Doc ID	Rev	Document description	Ph
P001-PRO-T-002	5	Electrical Design & Analysis	III
P001-PRO-T-003	8	Structural Verification Plan	III
P001-PRO-T-004	13	Structure Analysis Report for iSIM	III
P001-PRO-T-005	5	Thermal Analysis Report	III
P001-PRO-T-007	12	Standard Hazard Report of iSIM	III
P001-PRO-T-008	7	Unique Hazard Report of iSIM Structure Failure of iSIM	III
P001-PRO-T-009	12	Unique Hazard Report of iSIM Shatter able Material Release	III
P001-PRO-T-010	6	Unique Hazard Report of iSIM EVA Sharp Edge	III
P001-PRO-T-012	12	Material Usage Identification List	III
P001-PRO-T-018	5	EVA Touch Temperature of integrated Standard Imager for Microsatellites (iSIM)	III
P001-PRO-T-022	4	iSIM IOD Manufacturing and Inspection Record	III
P001-PRO-T-032	5	iSIM IOD FM - EMC Test Report	III
P001-PRO-T-034	0	iSIM IOD - Interface Test Report (GM/LEHX)	III
P001-PRO-T-037	1	iSIM IOD PFM - Vibration Test Procedure	III
P001-PRO-T-038	2	iSIM IOD FM - Thermal Test Procedure	III
P001-PRO-T-039	1	iSIM IOD FM - EMC Test Procedure	III
P001-PRO-T-040	5	iSIM IOD PFM - Vibration Test Report	III
P001-PRO-T-041	0	iSIM IOD FM - Thermal Test Report	III
P001-PRO-T-043	6	Fracture Control Summary Report	III

Doc ID	Rev	Document description	Ph
P001-PRO-T-046	2	iSIM Flight Safety Assessment Report for Phase III	III
P001-PRO-T-053	0	iSIM CoG & Mass Report	III
P001-PRO-T-054	0	iSIM IOD FM Vacuum Report	III
P001-PRO-T-055	0	iSIM IOD - Power consumption Analysis and Electrical Test Report	III
P001-PRO-T-061	1	iSIM IOD Manufacturing and Inspection Record (#2)	III
P001-PRO-T-067	3	Thermal Desktop Model Description Report	III
SATL-EHW-T-006-1	1	Bonding/Resistance Measurement Record	III
P001-PRO-T-016	3	IVA scenario	III+
P001-PRO-T-029	2	iSIM Packing and Launch Packing Plan	III+
P001-PRO-T-030	0	iSIM Packing Report	III+
P001-PRO-T-045	2	Certificate for Fasteners	III+
P001-PRO-T-052	2	iSIM IOD FM - ICD Inspection Report	III+
P001-PRO-T-057	0	iSIM IOD FM - Cleanliness Report	III+
P001-PRO-T-058	2	iSIM-iSEEP GM Interface Test Plan (#2)	III+
P001-PRO-T-062	0	iSIM-iSEEP GM Interface Test Report #2	III+
P001-PRO-T-066	0	Bonding/Resistance Measurement Record (MLI)	III+

With the final assembly, verification, and tests of the iSIM-170 FM completed, the beta cloth, i.e. the cover that will provide the thermal interface in i-SEEP, was tested for fitting (see Figure 27). Note that only the front part of the beta cloth covering the front plate and the fore baffles will remain for transport and launch, while the remaining parts will be installed at the ISS by an astronaut.

Figure 27: iSIM FM Thermal interface (beta cloth) fitting test.

Finally, iSIM-170 FM was packed first inside the launch container, then inside the transport case, and lastly inside the transport box (see Figure 28).

Figure 28: Transport box housing the launch container inside the transport case, surrounded by the SATLANTIS team.

The payload was shipped on the 28th of November. The official payload handover to JAXA took place on the 18th of December 2019 (Figure 29).

Figure 29: JAXA, Space BD and SATLANTIS personnel in Tsukuba during the iSIM-170 FM handover.

Prior to the iSIM-170 FM handover, the interface tests were repeated at JAXA facilities. The interface tests between iSIM and i-SEEP Ground Model yielded no significant issues or anomalies, both systems performed as expected and within the anticipated parameters.

Figure 30: Official handover ceremony with JAXA, SATLANTIS and Space BD representatives.

LAUNCH OF iSIM-170 FM TO THE ISS

Since the signature of the contract with Space BD, SATLANTIS has been working tightly with both JAXA and Space BD to comply with all the requirements for payload handling, deployment, and operation at the ISS. In parallel, a lot of effort has been destined, mainly by Space BD, to book and manage a slot within a suitable launch vehicle that can deliver iSIM-170 FM at the ISS as early as possible in 2020.

For securing a launch slot, Space BD had to notify JAXA on the desired launcher, then JAXA had to request the slot to the corresponding launch agency, and finally the launch agency had to confirm availability. For iSIM-170 FM, the first available option discussed between SATLANTIS and Space BD was the launch vehicle SpaceX Dragon (CRS-20), scheduled for March 2020. Therefore, this slot was notified to JAXA, and, since integration in this launcher is managed by NASA, JAXA then requested the slot to NASA.

In October 2019 NASA, JAXA, and Space BD confirmed the slot for iSIM-170 FM on board the CRS-20 mission, and correspondingly, SATLANTIS delivered the eLRODS document (which includes specification on the launch orientation). Following this plan, SATLANTIS delivered the iSIM-170 FM to JAXA on the scheduled date, 18th of December.

However, in January 2020 the NASA ISS Integration Office informed JAXA that iSIM-170 FM could no longer be installed in the CRS-20 in the designated launch orientation. SATLANTIS, understanding the potential risk implications of such sudden change, agreed to explore the next best option considering a balance between earliest launch opportunity and lowest technical and launch delay risks. The following figure summarises the tree of events and options that have taken place over the past months to reach the final solution.

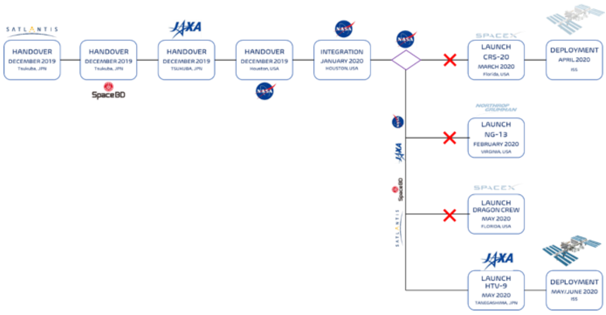

Figure 31: Sequence of events and options regarding the launch provider.

In the end, SATLANTIS selected the Japanese HTV-9 mission, and iSIM-170 FM was successfully launched on May20th, 2020 to the ISS from Tanegashima Space Center in Japan (Figure 32).

Figure 32: A Mitsubishi Heavy Industries H-IIB rocket launches the HTV-9 cargo module to the ISS from Tanegashima (credit: MHI/JAXA/NASA).

The HTV-9 "Kounotori" module arrived at the ISS in May 25th (Figure 33), and the iSIM-170 FM was transferred to interior of the ISS. It was installed on the i-SEEP platform on June 9th, 2020 and then transferred to the Exposed Facility of the Kibo module with the help of a robotic arm in June 11th, 2020.

Figure 33: HTV-9 module docked at the ISS in May 25th (credit JAXA/NASA).

iSIM-170 FM OPERATIONS AT THE ISS

After the iSIM-170 FM payload was installed at JEM EFU#5 and i-SEEP was powered-up, a complete Checkout sequence was performed. The iSIM-170 FM Checkout was carried out on Day 0 of nominal operations and lasted around 4 hours. The objectives of the Checkout were to verify that:

- i-SEEP detects power and iSIM-170 FM powers up
- iSIM properly sends telemetry to LEXH
- iSIM properly receives commands from LEXH
- iSIM properly receives schedule files via SFTP
- iSIM correctly sends data to PLCB2
- iSIM's telemetry is within the expected value ranges.

During this day, JAXA's server (J-PDDS) updated the telemetry data folder every 60s, and SATLANTIS did a *rsync* of that folder every 120s so that SATLANTIS operators could have live telemetry to assess the Checkout process. Nominal operations will last 91 days (13 weeks). Below, we briefly describe the operational constraints, an overview of iSIM-170 FM operations, the Tasks Plan, the Upload and Download Session Plan, and the Calibration Plan during nominal operations.

Before planning the operations, there are several constraints that need to be considered, including:

- iSIM-170's pointing is fixed on its position at the outside platform.
- In total, the maximum data to download is 149GB.
- Payload data can be downloaded a total of 21 times. Schedule files can be uploaded a total of 21 times.
- The Schedule File uplink and the Data Payload Files downlink will be executed via ISS Ku band communication.
- The downstream bandwidth is limited to 50Mbps and is to be shared among all payloads.

The general operational target for iSIM is to perform daily acquisitions consisting of seven sessions: six of 10 seconds duration each, and one of 3 minutes duration.

Based on the constraints imposed by the limited number of uploads and downloads, the operations of iSIM will be done through two different file types managed by the SmartCIAs:

- *Schedule Files:* to uplink and schedule commands to iSIM-170 FM, including when and how to carry out the acquisition sessions. Note that each SmartCIA will have its own schedule file.
- *Data Payload Files:* to download images, telemetry, and ancillary data generated by iSIM-170 FM. After the acquisitions, thumbnails of all acquired images will be generated and downloaded. Based on the thumbnails, SATLANTIS will select images for subsequent download at full resolution.

However, the upload and download sessions cannot be carried out at SATLANTIS only request, but have to be approved by NASA, since NASA manages and accommodates on a weekly basis all activities of the ISS. Therefore, a Task Plan has been set out to coordinate the approval of the upload and download sessions on a weekly basis, following a communication chain between SATLANTIS, JAXA and NASA. Once the upload and download sessions have been approved, the upload and downloads are carried out between SATLANTIS and JAXA according to the Upload and Download Session Plan.

Task Plan

NASA manages and accommodates on a weekly basis all activities of the ISS. Therefore, iSIM operations must be approved by NASA. The approval process is comprised of the Weekly Task Plan (WTP) and the Short Term Plan (STP), briefly described below.

Weekly Task Plan (WTP)

The WTP covers 7 days from Monday to Sunday and provides opportunities to make changes in iSIM-170 FM operations 3 times per week. These change requests must be sent to NASA, who accommodates the weekly plan of all ISS activities.

Short Term Plan (STP)

If some modifications and changes are needed after the Weekly Task Plan is fixed, the change request needs to be launched to NASA and input in the daily plan review at 6 days, 4 days, or 2 days before the execution of iSIM-170 FM operations.

Upload and Download Session Plan

Twenty one upload and twenty one download sessions will be carried out during the 91 days (13 weeks) of iSIM-170 FM operations. Once the weekly operations are approved, the Upload and Download sessions of the week are executed. The tasks to be carried out during the Upload and Download sessions include the following activities:

- Develop next schedule file & Downlink file list.
- Receive schedule file and reply to SATLANTIS.
- Console preparation.
- Check Telemetry data.
- Next schedules file upload to both SmartCIAs.
- Data Payload File downlink and store to JAXA server.
- Report to SATLANTIS.
- Console clean-up.
- Get Data Payload File from JAXA server.
- Check Data Payload File.

The maximum amount of data to be downloaded per session is 9GB (4.5GB per SmartCIA). The estimated duration of the 9GB downlink is 1 hour at 30 Mbps (or 2.5 hours at 15 Mbps, including some LOS between ISS and ground station).

In order to facilitate the real-time monitoring of the iSIM-170 FM payload and the implementation of the operations plan, SATLANTIS has developed several tools, including:

- *IOD Realtime Telemetry Website* to monitor IOD operations.
- *Operations GUI* to generate operations commands.
- *IOD Image Acquisition Website* to visualize and handle images.
- *LEXH Simulator* for ground testing.

An example of such tools is shown in the Figures below.

Figure 34: IOD Realtime Telemetry Website.

The IOD Realtime Telemetry Website (Figure 34) is a powerful tool developed by SATLANTIS to monitor iSIM-170 FM IOD operations. It receives near real-time telemetry (1h delay) every 10 seconds, which displays through a user-friendly interface that permits visualizing in a 2D World Map each orbit ground-track point for which telemetry was received. Telemetry data is classified according to four categories: iSIM General Performance, SmartCIA01 (Left Channel), SmartCIA02 (Right Channel), and SmartHeater. In addition, each category has the option to visualize the data either from a mission perspective to evaluate general trends in its critical parameters, or a rendered daily view for detailed analysis. Data is displayed through multiple plots such us Power Consumption, Voltage, Memory Storage, Temperature, or Commands Executed.

SATLANTIS has also developed a second user friendly interface called Operations Graphic User Interface (Figure 35) to automatize the generation of commands for iSIM image acquisition operations from CSV files containing a selection of targets, while still permitting the operator to modify both these commands and the parameters that define them.

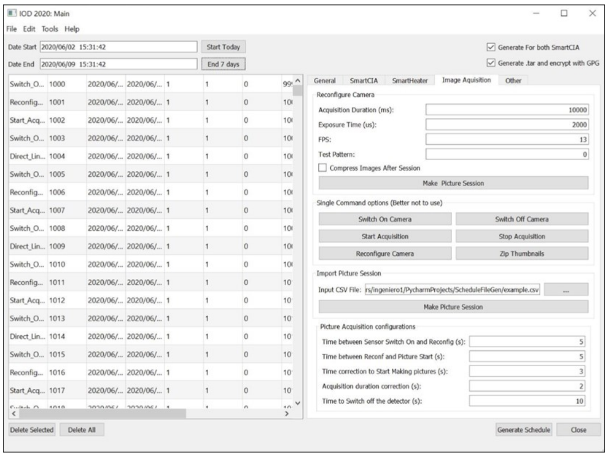

Figure 35: Operations GUI.

Calibration and Validation Plan

Calibration and validation activities are essential for the In-Orbit Demonstration of iSIM-170 FM technology, for quality assessment of the produced data, and for business development opportunities. The calibration and validation activities include checks and analysis of the functional and operational performance of iSIM's subsystems, on-orbit characterisation and verification of iSIM's subsystems, and assessment of the quality (radiometric, spatial and geometric) of the image products.

Table 6 lists the defined calibration and validation tasks planned for iSIM after Checkout is completed. The tasks are classified as: (1) characterisation of key parameters, i.e. the measurement of parameters representative of the system in operation; and (2) validation of functional and operational processes representatives of the functional behaviour of the system.

Table 6: iSIM-170 Calibration and Validation Tasks

Task	Data/Action required
Characterisation of key parameters	
Detector dark signal	Ocean areas at night.
Signal to Noise ratio (SNR) at different albedos	Homogeneous areas of different known albedos (e.g. deserts, ocean, asphalt, grassland) and sun elevation angles. Use available datasets such as USGS Catalog to select radiometric target sites.
On-orbit MTF and/or PSF	Large linear structures with sharp transition between bright and dark areas. Use datasets such as USGS Catalog to select spatial sites (natural and artificial targets).
Pixel and swath size	Urban areas with available cartographic data. Use datasets such as World Cities Database, and USGS Catalog Geometric Sites
Geolocation accuracy	Urban areas with available cartographic data. Use datasets such as World Cities Database, and USGS Catalog Geometric Sites
Average power consumption for the different operation modes.	Telemetry data.
Orientation of iSIM	Assuming that iSIM is pointing perfectly at Nadir, estimate the true orientation of payload using: - Images of coastal areas and urban areas with cartographic data - ISS ephemeris data (ISS position), clock (links image data to ephemeris and attitude) and attitude (ISS orientation).
Pointing knowledge (of the ISS)	Ephemeris data (ISS position), ISS clock and attitude data. Note that the ISS attitude will be considered constant throughout the mission. iSIM orientation
Validation of functional and operational processes	
Image acquisition process	Perform daily acquisitions of six sessions of 10 second duration each, and one session of 3 minutes duration.
Image download process	Generate thumbnails with lossy compression, crops with lossless compression, raw images with lossless compression, all including metadata.
On-orbit SW upgrade	Perform at least 1 SW upgrade and check correct implementation
Temperature stabilisation	Heat optomechanical structure at various temperatures (19ºC to 31ºC) and verify time required for stabilisation
Validation of on-ground image geolocation process	Images of urban areas with available cartographic data, ancillary information (ephemeris, altitude,

Task	Data/Action required
	clock, alignment)
Validation of on-ground sensor radiometric correction process	Images with high SNR, well documented (e.g. PICS), and covering an area covered by other available satellites for comparison (e.g. Sentinel, Landsat), sensor specs (conversion gain, photosensitivity), acquisition parameters.

Note that the calibration and validation plan will be reviewed and updated on a regular basis as required by the mission and considering the operational constraints and operations plan.

Two important aspects limit the planning of the calibration and validation schedule: (1) the fact that iSIM-170 FM has fixed pointing as determined by the ISS; and (2) the fact that SATLANTIS does not have direct real-time nor direct access to iSIM-170 FM at the ISS.

The inability to point iSIM impacts the coverage all of relevant targets relevant target, reducing the chances of a flyover and stressing the importance of a prior target analysis. Therefore, SATLANTIS has simulated the ISS orbit over the expected time period of operation and has mapped the corresponding scan area of iSIM-170 FOV on the Earth's surface.

In parallel, a database of relevant targets worldwide has been compiled, based on catalogues such as USGS Catalog and World Cities Database. Lastly, iSIM-170's scan area has been cross-correlated with the database to retrieve the location and timestamp of targets that fall within iSIM-170's FOV. Note that this analysis will determine the frequency with which SATLANTIS can carry out some validation and calibration tasks.

On the other hand, the restrictions on SATLANTIS access to iSIM-170 FM requires image acquisition instructions to be planned and scheduled well in advance (see sub-section on Upload and Download Session Plan above). The files to be uploaded are the Schedule Files which contain the commands to operate iSIM-170 FM and include instructions on when, how and with which parameters iSIM-170 FM should carry out image acquisitions.

Currently, operations have been preliminarily defined at high level. Nevertheless, note that the operations for each week will be planned by using the tentative plan as reference and adapting it based on the needs and results of previous weeks. If all goes well, as expected, we plan to show the first science-quality EO images taken with iSIM-170 FM on board the ISS at this Conference.

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