MOSAR

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Lead Partner	:	Space Applications Services
Abstract	:	This document is the Design Definition File of HOTDOCK, the mating standard interfaces implemented in the projects PRO-ACT, PULSAR and MOSAR. The document covers the operational implementation in the project demonstrators, the key aspects of the design and the specifications of the interface.
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DOCUMENT CHANGE RECORD

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1.0.0	14/05/2020	Space Applications Services MAG SOAR	All	First Release for EC/PSA review
1.1.0	25/08/2020	Space Applications Services	4.1.2 4.1.3 4.2.3.1	Clarification of HOTDOCK mass properties, following RID OG09-126 Clarification on misalignment combination, as feedback to RID OG09-127 Additional information on HOTDOCK magnet sensors and orientation detection, as feedback to RID OG09-128

Contents

List of Figures

List of Tables

1 Introduction

1.1 Purpose and Scope

HOTDOCK is a standard robotic interface, developed by Space Applications Services, supporting mechanical, data, power and thermal transfer. Its final purpose is to be used as standard connector, in future space applications, between spacecraft and payloads, and as end effector of robotic manipulator for their manipulation and transfer.

The purpose of this document is to provide information about the design of the HOTDOCK device that will be implemented as standard interface in the H2020 MOSAR (OG9) project, as well as in H2020 PULSAR (OG8) and H2020 PRO-ACT (OG11). By releasing this material publicly, the aim is to diffuse the design information in the community to leverage the deployment of HOTDOCK, as building block, in future H2020 Space Robotics Technologies SRC calls, but also in projects for Space (orbital and planetary) or Erath applications.

1.2 Document Structure

In brief, the document is structured as follows:

Chapter 1 **Introduction**, this section presenting the purpose of the document and reference information

Chapter 2 **HOTDOCK System Overview,** introduces and defines the HOTDOCK device and declinations

Chapter 3 **OGs Demonstrators Operational Scenarios,** summarizes the use of HOTDOCK in the on-going OG's activities

Chapter 4 **HOTDOCK Detailed Design,** presents the overall design of HOTDOCK, including the mechanical design, the mechanical/data/power/thermal interfaces, the controller and software

Chapter 5 **HOTDOCK Requirements Compliance Analysis**, provides the compliance matrix and reference to section for the SRC and OGs projects requirements that have been used to guide the design of HOTDOCK.

Chapter 6 **Reference Drawings**, provides detailed information about the HOTDOCK mechanical design and characteristics, envelope, mounting interfaces

1.3 Applicable Documents

AD1 SRC_Guidelines_Space_Robotics_Technologies (COMPET-4-2016)

AD2 PRSPR-ESA-T3.1-TN-D3.1-Compendium of SRC activities (for call 1)-v1.8_0

AD3 PULSAR (OG8) Grant Agreement

AD4 MOSAR (OG9) Grant Agreement

AD5 PRO-ACT (OG11) Grant Agreement

1.4 Reference Documents

RD1 D3.8 - HOTDOCK Design Justification File

1.5 Acronyms

ADC	Analog to Digital Convertor
Bps	Bit per second
cPDU	centralized Power Distribution Unit
CLT	Client Spacecraft
CNC	Computer Numerical Control
COG	Centre of Gravity
DDF	Design Definition File
DJF	Design Justification File
dPAMT	demonstrator of Precise Assembly of Mirror Tiles
EGSE	Electrical Ground Support Equipment
FMC	FPGA Mezzanine Card
HK	House Keeping
HW	Hardware
IF	Interface
ISRU	In-Situ Resource Utilization
JTAG	Joint Test Action Group
LVDS	Low-voltage differential signaling
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
N.A.	Non Applicable
NPT	National Pipe Thread
OBC	On-Board Computer
OBDH	On-Board Data Handler
OG	Operational Grant
PCB	Printed Circuit Board
RAS	Robotic Arm System
R-ICU	Reduced Interface Control Unit
ROD	Review of Design
SI	Standard Interface
SM	Spacecraft Modules
SMT	Segmented Mirror Tiles
SpW	SpaceWire
SRC	Strategic Research Cluster
SVC	Servicer Spacecraft
SW	Software
TBC	To be Confirmed
TBD	To be Defined
TC	Telecommand
TM	Telemetry
WM	Walking Manipulator

2 HOTDOCK System Overview

2.1 Introduction

HOTDOCK is a standard robotic mating interface supporting mechanical, data, power and thermal transfer, in active and passive configurations (Figure 2-1). Its main application is to allow assembly and reconfiguration of spacecraft and payloads on-orbit and on planetary surfaces. It makes it straightforward to replace failed modules, or to swap payloads and provide chainable data interfaces for multiple module configurations.

A full feature HOTDOCK device provides the following interfaces, as illustrated in Figure 2-1:

- The mechanical interface that provides the alignment, connection and mechanical load transfer capabilities. It is composed of fixed elements (main body structure, form fit geometry) and a movable locking ring to allow connection with another device.
- The power interface, for the transfer of electrical power, through the central interface plate and POGO pin connectors.
- The data interface, for the transfer of CAN or SpW data, through the central interface plate and POGO pin connectors.
- The thermal interface, allowing fluid transfer between two devices.

HOTDOCK includes also its own internal PCB controller for local management (actuators, sensors, TM/TC communication) and connectors on the back, to access the power/data interface pins and the internal controller/powering of the device.

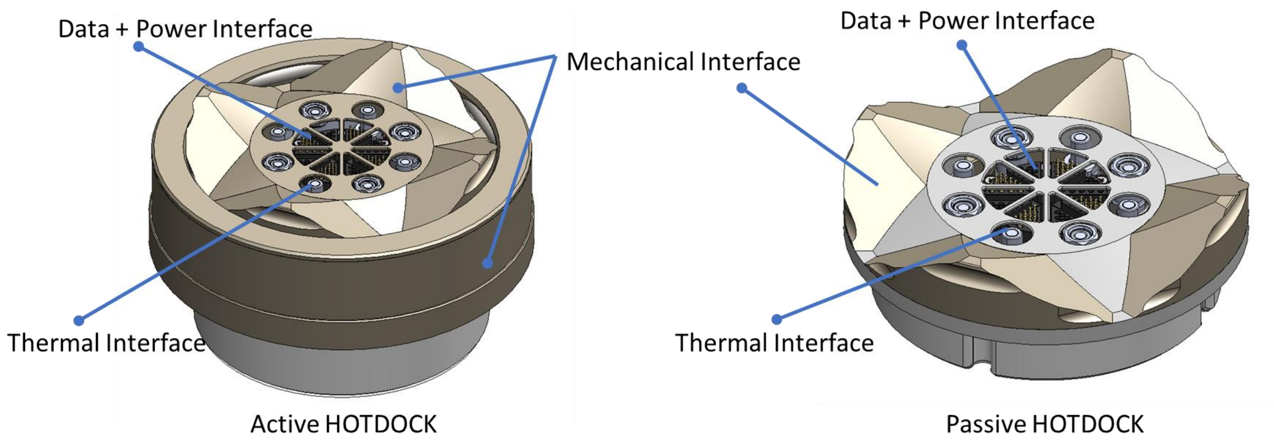


Figure 2-1: HOTDOCK Standard Interface (in Active and Passive configurations)

2.2 HOTDOCK Declinations

HOTDOCK exists in different declinations, as function of the type of transfer capabilities.

Table 2-1 summarizes the different declinations:

- **HOTDOCK A (Active)**: provides the form-fit geometry, the active locking mechanism and the deployable power/data interface plate, with motor and PCB controller.
- **HOTDOCK AT (Active Thermal)**: active version including also thermal interface for fluid transfer
- **HOTDOCK P (Passive)**: simplified version of the active, which provides the form-fit geometry and a fixed power/data interface plate. There is no moving plate
- **HOTDOCK PT (Passive Thermal)**: passive version including also thermal interface
- **HOTDOCK M (Mechanical)**: simplified version, which provides only the for-fit geometry (no power/data interface plate or moving components)
- **HOTDOCK D (Dummy)**: 3D printed version for visual rendering (no mechanical load transfer)

Table 2-1: Features of the different declination of HOTDOCK

	Name	Visual	Mating	Mechanical Transmission	Data Transmission	Power Transmission	Thermal Transmission
	Active	✓	✓	✓	✓	✓	
	Active Thermal	✓	✓	✓	✓	✓	✓
	Passive	✓		✓	✓	✓	
	Mechanical	✓		✓			
	Dummy/Visual	✓					

The active declinations (HOTDOCK A and HOTDOCK AT) enable the mating process and are required to connect to another HOTDOCK device. The following connection options are possible, between two HOTDOCK declinations:

- **Active (Thermal) to Active (Thermal)**: for mechanical load, power, data (and Thermal) transfer
- **Active (Thermal) to Passive (Thermal)**: for mechanical load, power, data (and Thermal) transfer (the Active HOTDOCK plate is able to go in contact with the Passive connectors)
- **Active to Mechanical**; for mechanical load transfer

In terms of integration in the current projects, as well for future exploitation, the passive and mechanical versions have high interest, especially when talking about payload operations:

- They are smaller in height and lighter
- There is no active components (actuator, electronics)
- They are less expensive
- They be installed on a spacecraft/satellite with less integration constraints, waiting for an active one to connect to it (e.g. as part of a next mission). We think that this can be a great advantage for the early exploitation and diffusion of the technology (very low impact on spacecraft design)
- The reduced complexity and price of the passive/mechanical versions will facilitate the integration of more interfaces and connection points.

- The mechanical version (without the central connector plate for data and power), can be envisaged when we need only to manipulate items (e.g. beam structures)

2.3 Product Tree

Figure 2-2 presents the top level HOTDOCK product tree, highlighting the main components of the product. The design description of these components is provided in the following sections.

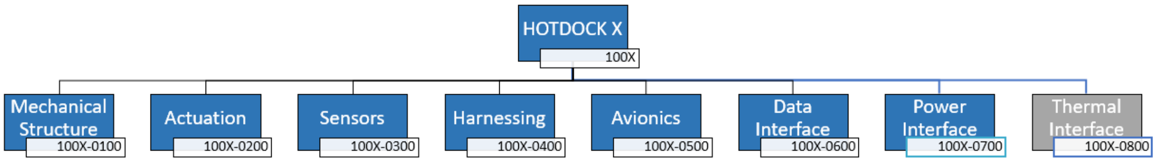


Figure 2-2: HOTDOCK Product Tree

3 OGs Demonstrators Operational Scenarios

3.1 OG8 – PULSAR Operational Scenario

Autonomous assembly of large structures in space is a key challenge towards the implementation of future missions that will require structures to be self-deployed as a single piece. PULSAR's (Prototype of an Ultra Large Structure Assembly Robot) objective is to develop and demonstrate key technologies for in-space assembly of the primary mirror of a large telescope.

As one of the main objective of the PULSAR project, the goal of the dPAMT ground setup is to demonstrate the precise assembly of Segmented Mirror Tiles (SMT) interconnected with HOTDOCK standard interface, and the functionality of the active SMT mirror adjustment system. Figure 3-1 illustrates the dPAMT architecture, the design of the SMT assembly and the Robotic Arm System (RAS)

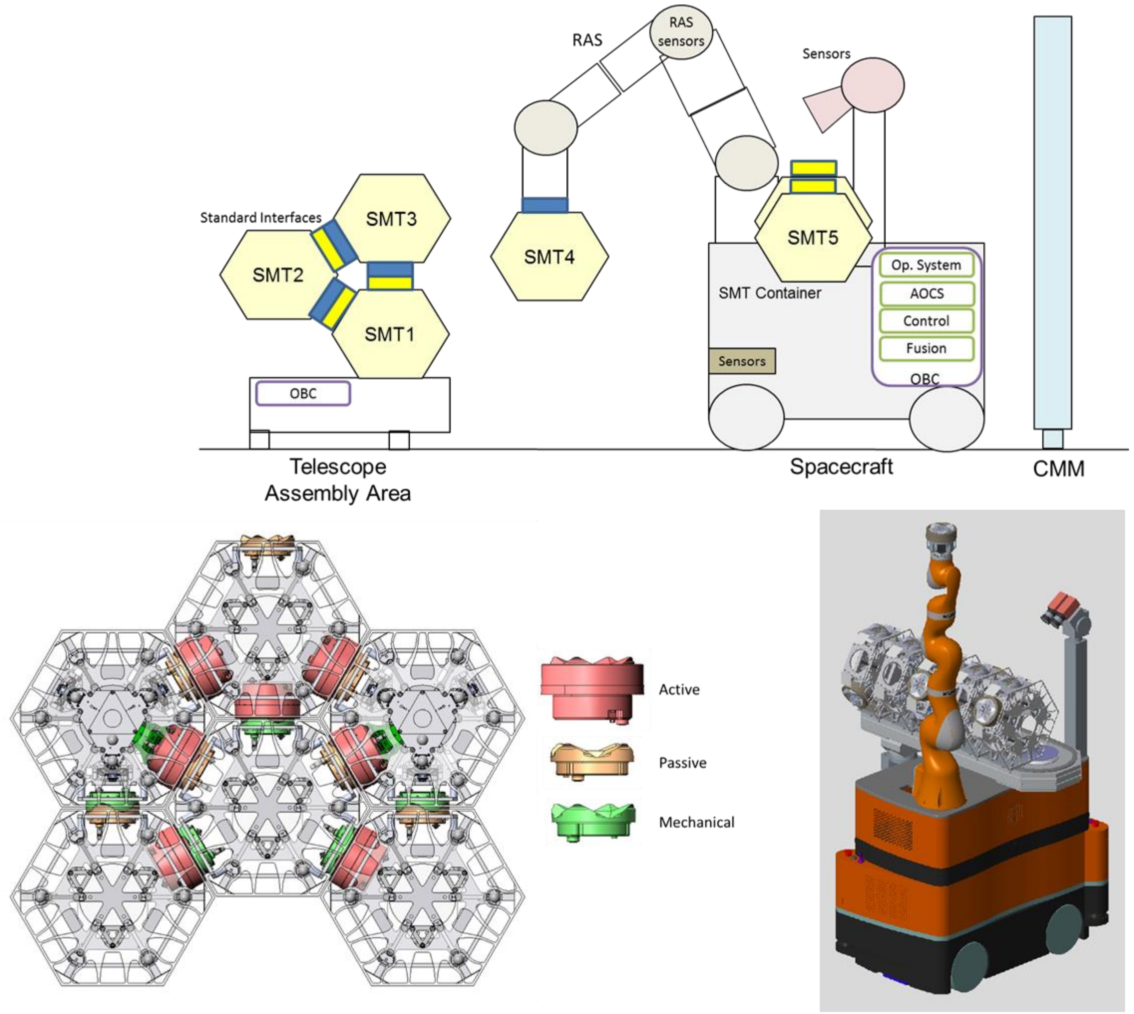


Figure 3-1: PULSAR dPAMT Architecture, mirror assembly of dSMTs (credit @ PULSAR/CSEM) and Robotic Assembly System (RAS, credit @PULSAR/DLR)

HOTDOCK is used in two distinct phases of the demonstration:

1. **Mirror Assembly**

   Equipped with an active HOTDOCK at the end-effector, the RAS connects to and transfers successively the SMTs, from a storage container to the final position in the segmented mirror setup. Once connected to one of the HOTDOCK of the tile, the robot OBC is able to control the other SMT active HOTDOCK(s) through the data and power interface of the RAS end-effector HOTDOCK. This allows the connection to the other tiles already in place. Once assembled, HOTDOCK ensures the structural integrity of the full segmented mirror.

2. **Operation and control of the SMT positioning system**

   After the full assembly is done, the HOTDOCKs, that interconnects the SMTs, support the power and data transfer from the segmented mirror OBC to the active mirror positioning system, localized on the tiles, to enable its operation and control.

Figure 3-2 illustrates the power and data architecture of the dPAMT demonstrator. It has to be noted that, to simplify the diagram, its doesn't correspond to the real SMT configurations selected for the demonstration.

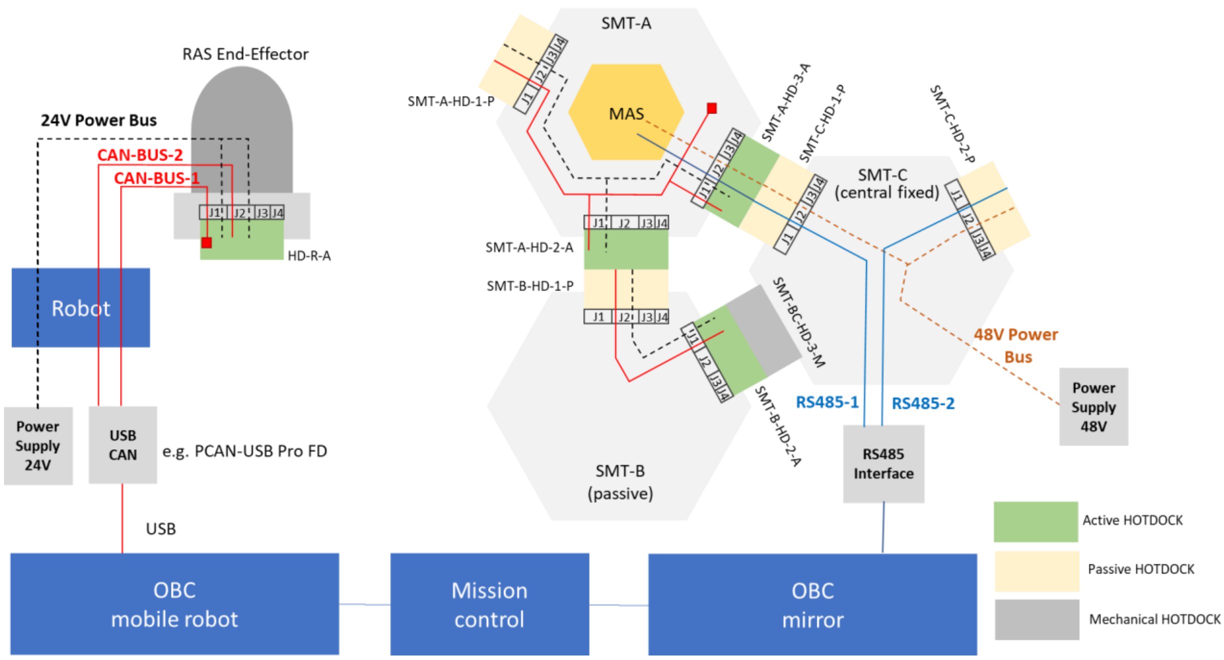


Figure 3-2: PULSAR dPAMT demonstrator data and power architecture

During assembly, the mobile robot OBC is responsible to control the RAS, as well as the active HOTDOCK interface equipped on its end-effector, through the CAN-1 bus interface. The HOTDOCK controller gets also power from a 24V power supply. Once connected to another SMT HOTDOCK (typically passive), the CAN-2 bus, transferred through the HOTDOCK data interface plate, is extended to the other active HOTDOCKs on the tile, such that they can be operated from the robot OBC. The 24V power line is also driven through the power transfer interface, passing through a bidirectional switch in HOTDOCK that can control the powering of the HOTODOCKs on the tile. Through monitoring of the HOTDOCKs telemetry and states, the mission control can autonomously trigger the successive steps of the assembly operations.

During operation, the active mirror positioning system, powered by a 48V power bus is controlled by the mirror OBC, through a RS-485 bus. Both data and power buses are transferred through the connected HOTDOCK interfaces. The HOTDOCK interfaces does not need to be powered during these operations and act as passive plugs.

The following table summarizes the list of HOTDOCK interfaces implemented in the demonstration and their declinations:

Table 3-1: Summary of HOTDOCK devices integrated with PULSAR dPAMT components

Component	Active	Passive	Mechanical
Robotic Assembly System	1	0	0
dSMT1	0	2	3
dSMT2	1	1	0
dSMT3	1	1	0
dSMT4	1	1	1
dSMT5	1	1	1
dSMT6	3	1	0
Total	**8**	**7**	**5**

3.2 OG9 – MOSAR Operational Scenario

The technologies developed in MOSAR aim to support the development of fully modular and on-orbit reconfigurable spacecraft. The baseline scenario is the one of a Servicer Spacecraft (SVC) transporting a cargo of Spacecraft Modules (SM) and a dedicated Walking Manipulator (WM). This last enables a number of operations with the transfer of SM from and to the Client Spacecraft (CLT), with the purpose of adding, replacing or enhancing client platform or payload functionalities. Figure 3-3 illustrates the mission baseline scenario and the transition to the mock-up ground demonstrator.

The HOTDOCK standard interface is used in MOSAR to inter-connect all the components of the system and enable their manipulation, fixation and data/power/thermal transfer:

- Equipped with HOTDOCK interfaces, the servicer spacecraft and the client satellite bus provides the structure for respectively the transfer of the spacecraft modules and assembly of the client satellite.
- The walking robotic arm manipulator allows the transfer and arrangement of the modules on the structures. Equipped with HOTDOCK interfaces at both end, it is able to connect to the modules, as well as, to walk along the spacecraft structure.
- The spacecraft modules, simulating payloads and equipment, are equipped with HOTDOCK interfaces to enable their connection to the spacecraft, the manipulator and the other modules.

The demonstration, foresee to demonstrate mechanical, data (SpaceWire), power and active fluid thermal transfer through HOTDOCK interfaces between the different components.

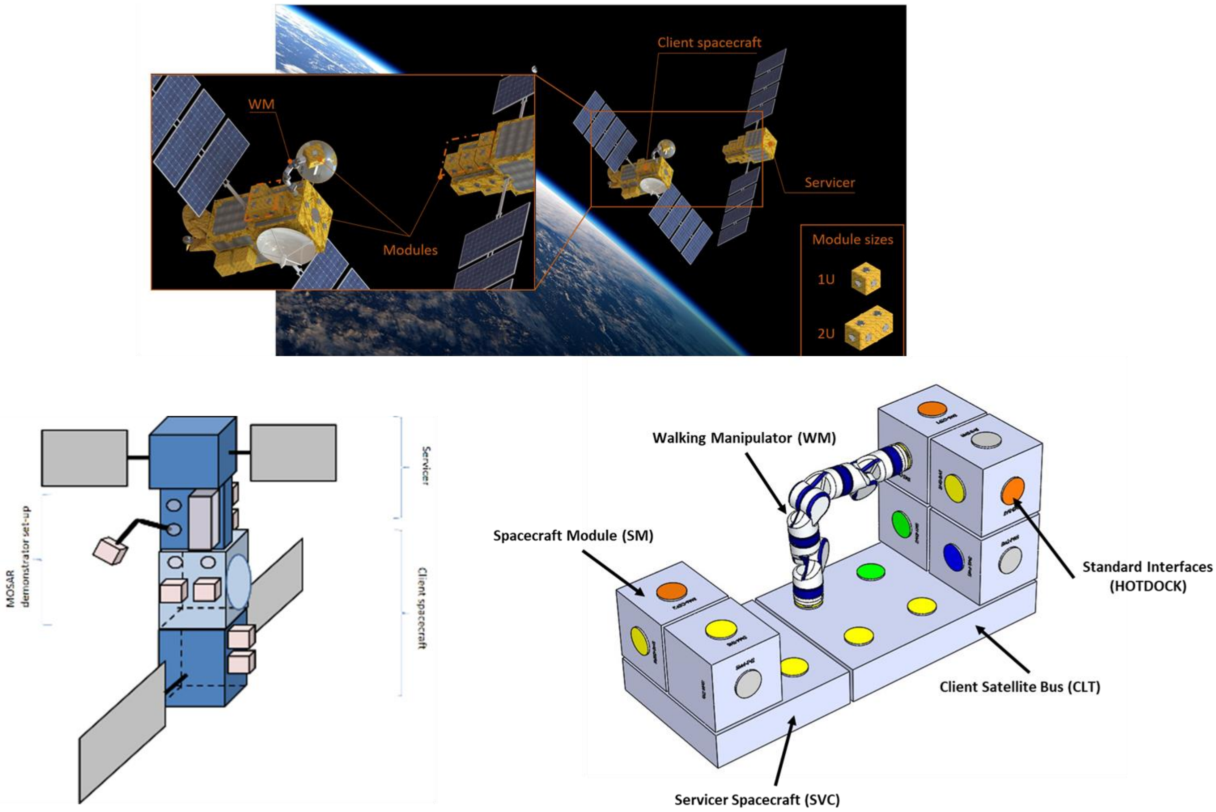


Figure 3-3: MOSAR baseline scenario and ground demonstrator main components

Figure 3-4 illustrates the typical data and power architecture of a spacecraft module. A similar strategy is applied for the other components that are the spacecraft, satellite and walking manipulator.

The HOTDOCK interfaces implement the Space Wire data transfer between the spacecraft modules. Internally, each interface is connected to the R-ICU/FMC router to enable the communication between the modules and the spacecraft OBCs. The same apply with the power transfer, but this time, through internal connection with the cPDU, which plays the role of power distribution and conversion in the module. Beside the internal components of the module, the power is also re-distributed to the other HOTDOCK interfaces to enable a power network along the full structure. This is also managed though implementation of power switches to control the power transfers (in the HOTDOCK or cPDU).

In each modules, the R-ICU (brain of the module) is responsible to control the active HOTDOCK interfaces, and get the telemetry, through CAN communication. Either the commands are generated locally by the R-ICU, or from higher-level commands coming from the spacecraft OBCs, through the SpW data interface.

In the case of the Thermal spacecraft module (illustrated in the Figure), the R-ICU manages also the Thermal sub-system that controls the active thermal transfer between the Active HOTDOCK and a second module.

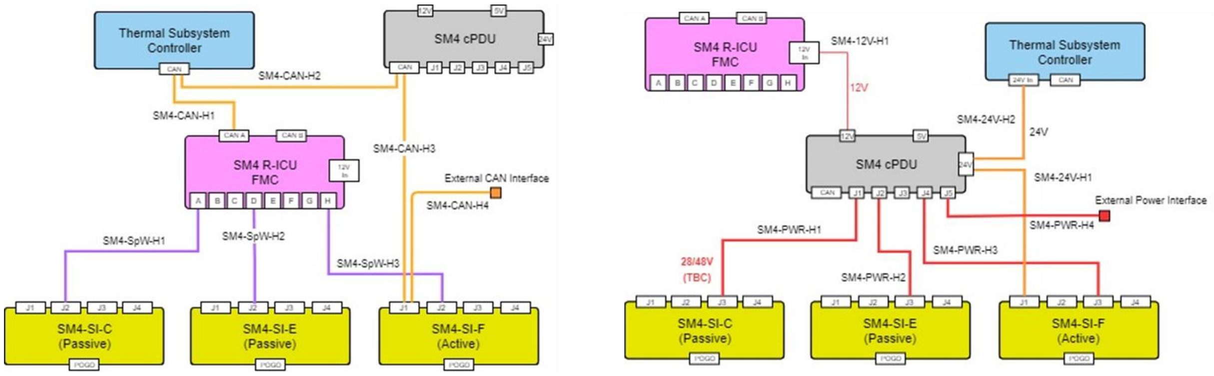


Figure 3-4: Typical data and power architecture of a spacecraft module equipped with HOTDOCK

The following table summarizes the list of HOTDOCK interfaces implemented in the demonstration and their declinations:

Table 3-2: Summary of HOTDOCK devices integrated with MOSAR components

Component	Active	Active Thermal	Passive	Passive Thermal	Mechanical
SVC	0	0	2	0	2
CLT	1	0	3	0	0
Walking Manipulator	2	0	0	0	0
SM1-DMS	2	0	0	0	0
SM2-PWS	0	0	1	1	0
SM3-BAT	1	0	2	0	1
SM4-THS	0	1	2	0	1
SM5-OSP1	1	0	2	0	0
SM6-OSP2	1	0	3	0	1
Total	**8**	**1**	**15**	**1**	**5**

3.3 OG11 – PRO-ACT Operational Scenario

The general goal of PRO-ACT is to showcases the autonomous deployment of an In-Situ Reutilization Unit on the Moon surface performed using robotic devices. The demonstration will be based on the deployment of several robotic platforms, including VELES (PIAP Space) and Mantis (DFKI).

The main application of HOTDOCK in PRO-ACT operations is to be integrated as end-effector interface for the VELES robotic platform, to enable end-effector tool adaptation (active gripper, driller, passive construction tools) or direct manipulation of ISRU elements, to support the assembly process. The next Figure illustrates the integration of HOTDOCK in the different PRO-ACT components.

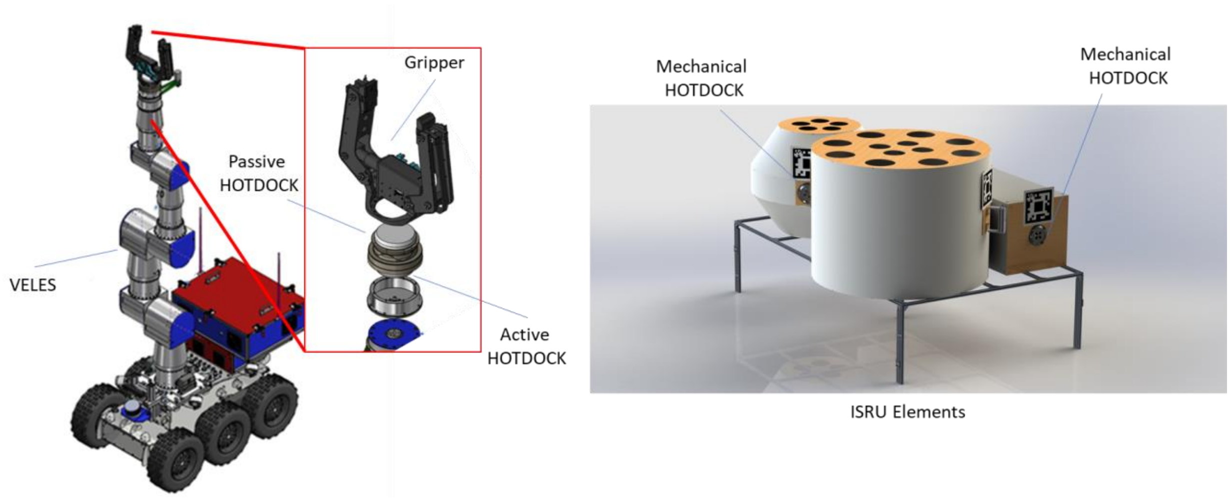


Figure 3-5: Integration of HOTDOCK interface in PRO-ACT components (VELES and Gripper pictures @PRO-ACT/PIAP SPACE)

The following table summarizes the list of HOTDOCK interfaces implemented in the demonstration and their declinations:

Table 3-3: Summary of HOTDOCK devices integrated with PRO-ACT components

Component	Active	Passive	Mechanical
VELES Robotic Manipulator End-effector	1	0	0
Active Gripper	0	1	0
Active Driller	0	1	0
Passive Robot Tool	0	0	1
ISRU Elements	0	0	3
Total	**1**	**2**	**4**

The Active HOTDOCK integrated as end-effector of the VELES manipulator is able to connect to:

- the Passive HOTDOCK integrated with the Gripper, to enable power and control of it through the data and power interface
- the Passive HOTDOCK integrated with the Driller, to enable power control of it through the interface
- the mechanical HOTDOCK fixed on the ISRU elements, to provide a mechanical connection for manipulation of them (in collaboration with MANTIS).

The following picture illustrates the data and power architecture around the HOTDOCK interface in PRO-ACT in the case of the connection with the Gripper/Tool.

The VELES Control unit provides two CAN interfaces, one for controlling and monitoring HOTDOCK (SI CAN Control) and the second one for the communication with the Gripper/tool. Once the Active HOTDOCK on the end-effector is connected to the Passive one on the gripper, the Arm Control Unit is then able to communicate with the Gripper controller by CAN.

The robotic platform power supply delivers the power of HOTDOCK through the 24V line (with a switch to power on/off the HOTDOCK interface). It also provides the power for the Gripper (48V line) that is transferred through the HOTDOCK power transfer plate. An external control switch is foreseen to enable/disable the power transfer to the tool. This is also optionally possible with the embedded relay in the HOTDOCK interface (up to 8A).

In the case of the connection of the HOTDOCK end-effector to a mechanical device, only the SI CAN control and 24V power lines are used to operate and power the Active HOTDOCK.

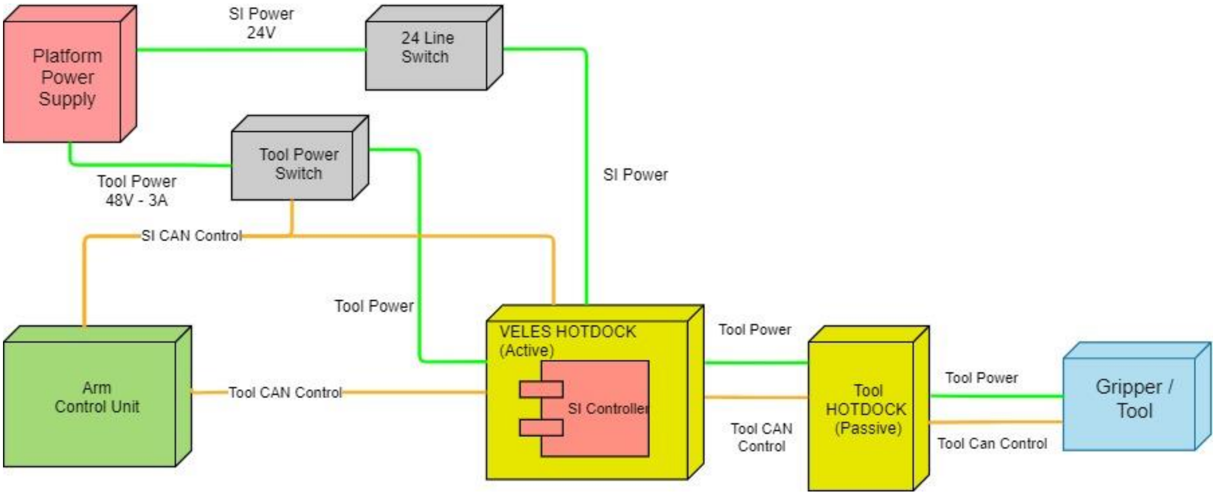


Figure 3-6: HOTDOCK data and power architecture in PRO-ACT / VELES

4 HOTDOCK Detailed Design

4.1 General Description

This section describes the general characteristics of the HOTDOCK device and its operation, for the active and passive declinations (mechanical version being the same as the passive, without the central connector plate).

4.1.1 Coordinate System and Dimensions

The coordinate system selected for HOTDOCK envelope is depicted in Figure 4-1 and Figure 4-2, respectively for the Active and Passive version. The coordinate centre O is on the centre point of HOTDOCK diameter of HOTDOCK bottom plate. The Figures also highlight the general dimensions of the device, including the back volume that covers the controller electronics and the back connectors.

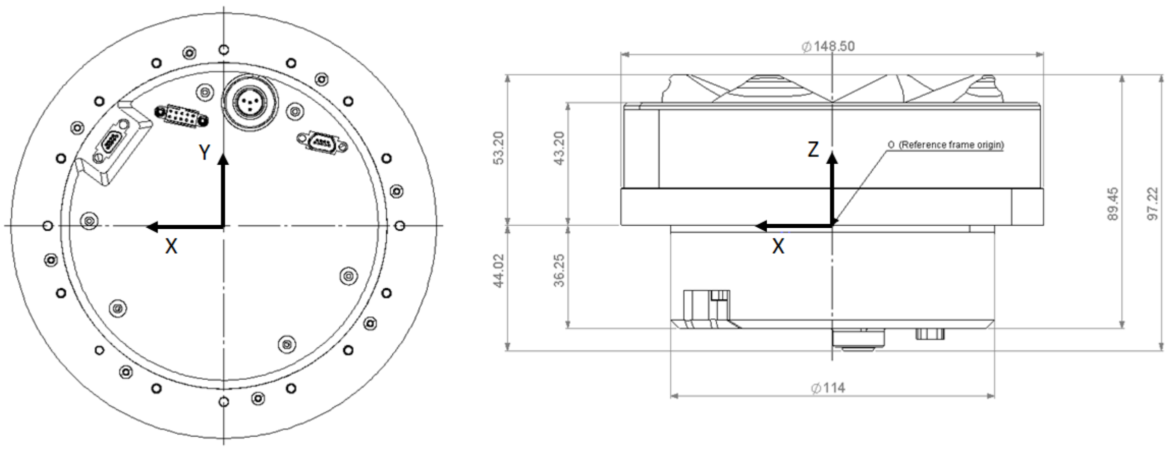


Figure 4-1: Active/Active Thermal HOTDOCK Coordinate system definition

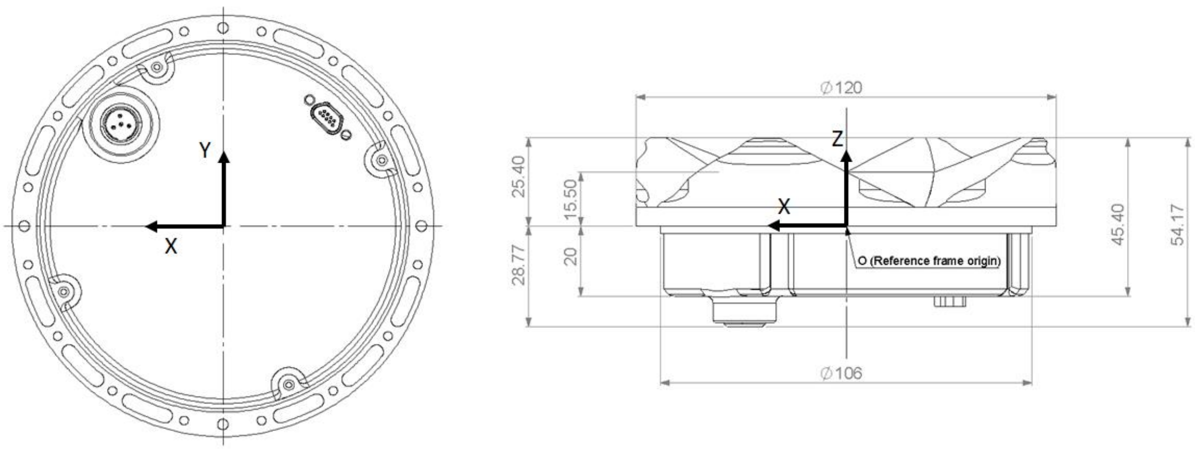


Figure 4-2: Passive/Passive Thermal HOTDOCK Coordinate system definition

4.1.2 Mechanical Specifications

The mass properties of each HOTDOCK version are (including all internal components):

HOTDOCK type	A	AT	P	PT	M
Mass (Kg)	1.45	1.60	0.35	0.50	0.25
Uncertainty (%)	+/- 10	+/- 10	+/- 10	+/- 10	+/- 10

The centre of gravity location of each HOTDOCK is defined w.r.t. the centre of the relative mechanical reference frame such that:

HOTDOCK type		A	AT	P	PT	M
COG coordinates (mm)	X	0	0	0	0	0
	Y	0	0	0	0	0
	Z	+18.3	+16.9	+8.7	+3.1	+10.2

Intertia characteristics of HOTDOCKs , taken at the centre of the coordinate system are:

HOTDOCK type		A	AT	P	PT	M
Inertia properties (g.mm2)	Ixx	2766056	2335433	366399	441381	339650
	Iyy	2750548	2327918	366737	443784	339650
	Izz	3760065	3126147	664555	779023	613290

4.1.3 Misalignment Tolerances and Approach Angle

4.1.3.1 Misalignment Tolerances

Misalignment tolerances are split in two scenarios.

1) Misalignment tolerance when two sides are approaching by external guidance (e.g. robotic system).
2) Misalignment tolerance acceptable when starting coupling procedure.

Figure 4-3 and Figure 4-4 shows the maximum misalignment tolerances of the Form-Fit geometry when two interfaces are approaching. The presented figures are based on preliminary motions studies performed by DLR, using a compliant robotic manipulator. These tests were performed individually for each misalignment. Combination of translation and rotation ROA is expected but needs further tests to validate.

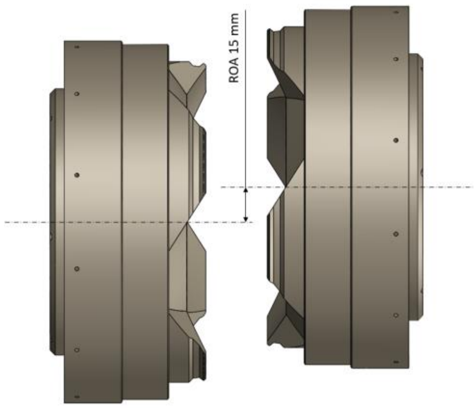


Figure 4-3 HOTDOCK – Range of attraction (ROA) supported by Form-Fit geometry.

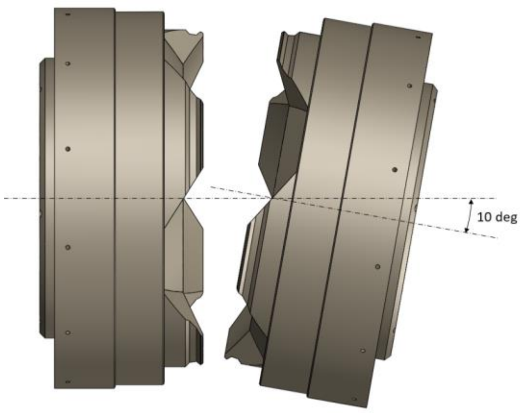


Figure 4-4 HOTDOCK – Max angular misalignment.

Figure 4-5 shows the acceptable, remaining distance before the coupling procedure can be initiated. While coupling, both HOTDOCK interfaces will force each other into their final coupling position, that remains without gap.

Figure 4-5 HOTDOCK – Max gap before locking.

4.1.3.2 Approach angle

The form-fit is designed to support straight and diagonal coupling trajectory up to 63 degrees (up to an aperture angle of 126 degrees), compatible with three simultaneous approach in hexagonal structure shape.

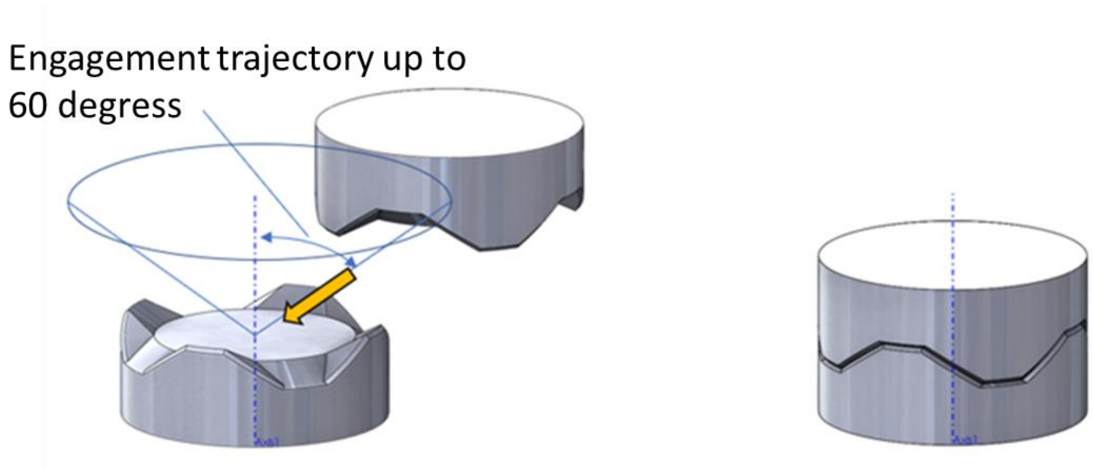


Figure 4-6: Diagonal Engagement Trajectory

4.1.4 Mounting and Fixation Layout

4.1.4.1 Materials and surface treatments

- For HOTDOCK A/AT/P/PT/M
  - Interface material: Aluminium 6061
  - Surface treatment: Nickel coated 10 microns
- For HOTDOCK D
  - Interface material: PLA
  - No surface treatment

4.1.4.2 Mounting References

Mounting references and instructions are depicted in Figure 4-7 and Figure 4-8 of each HOTDOCK version. This includes:

- Mounting reference surface (size, flatness, roughness) and holes (position, dimensions, tolerances)
- Mounting pin definition (position, dimensions, tolerances)
- Fasteners (position, dimensions)

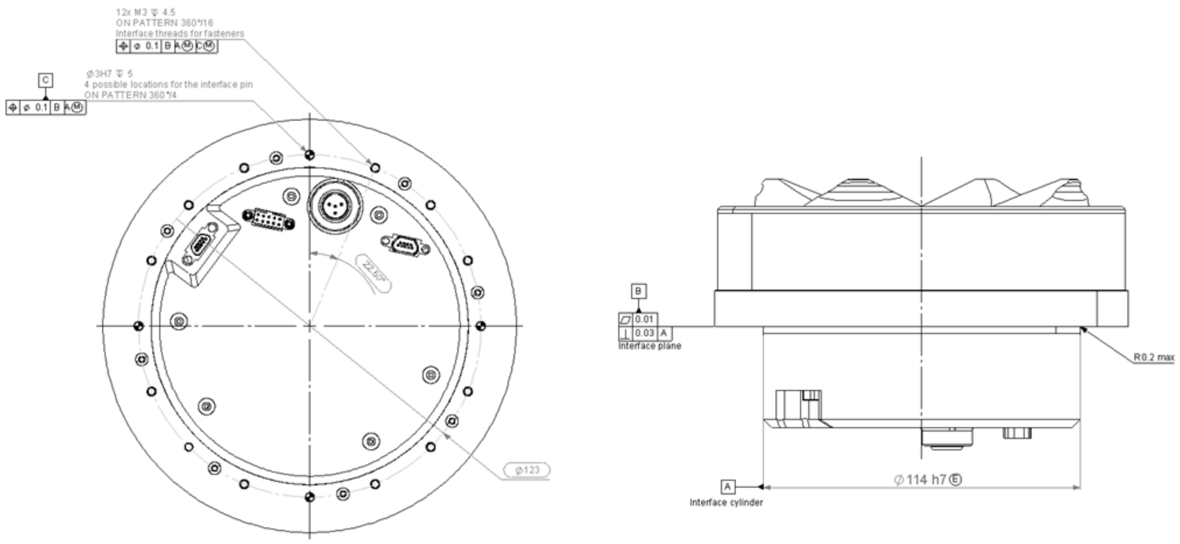


Figure 4-7: Active/Active Thermal HOTDOCK mounting reference

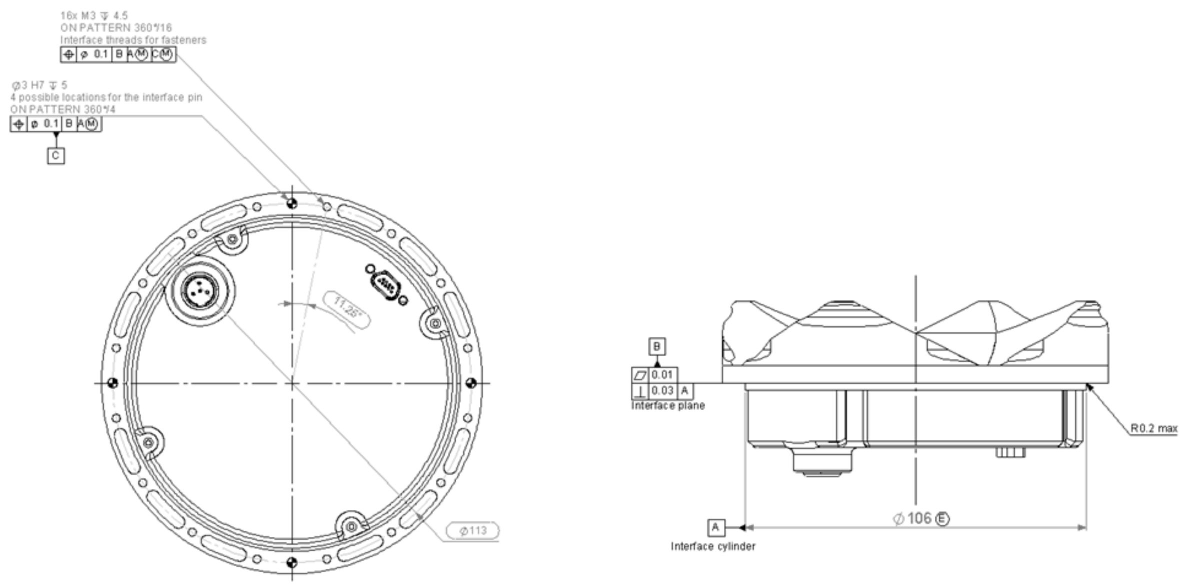


Figure 4-8: Passive/Passive Thermal HOTDOCK mounting reference

4.1.5 HOTDOCK Operational States

Figure 4-9 illustrates the nominal sequence of operation of an active HOTDOCK and the associated states of the powering, latching and connection:

- **Offline**: the device is neither powered, latched or connected for data and power transfer (e.g. when the HOTDOCK is not used).
- **Idle**: the device is powered, able to exchange CAN TM/TC with its master controller but not latched nor connected for data and power transfer.
- **Latched**: the device is powered and mechanically latched to another HOTDOCK (active, passive or mechanical). The connector/thermal plate is not deployed.

- **Connected**: the device is powered, latched and connected for data, power and optionally thermal transfer. The connector plate is deployed to get contact with the other HOTDOCK connector plate. For the case of an Active to Passive connection, the active connection plate is fully extended. In the case of an Active to Active connection, the design is compatible with two options. Either one of them can be fully extended or both could extend to the middle of the translation (as function of the operational requirements)
- **Locked**: the device is powered off, while in connected mode (e.g. when the full connection operation is finished). Both interfaces can transfer mechanical loads and power. Data transfer is function of the type of the bus technology and the need of active routing to manage the device symmetry.

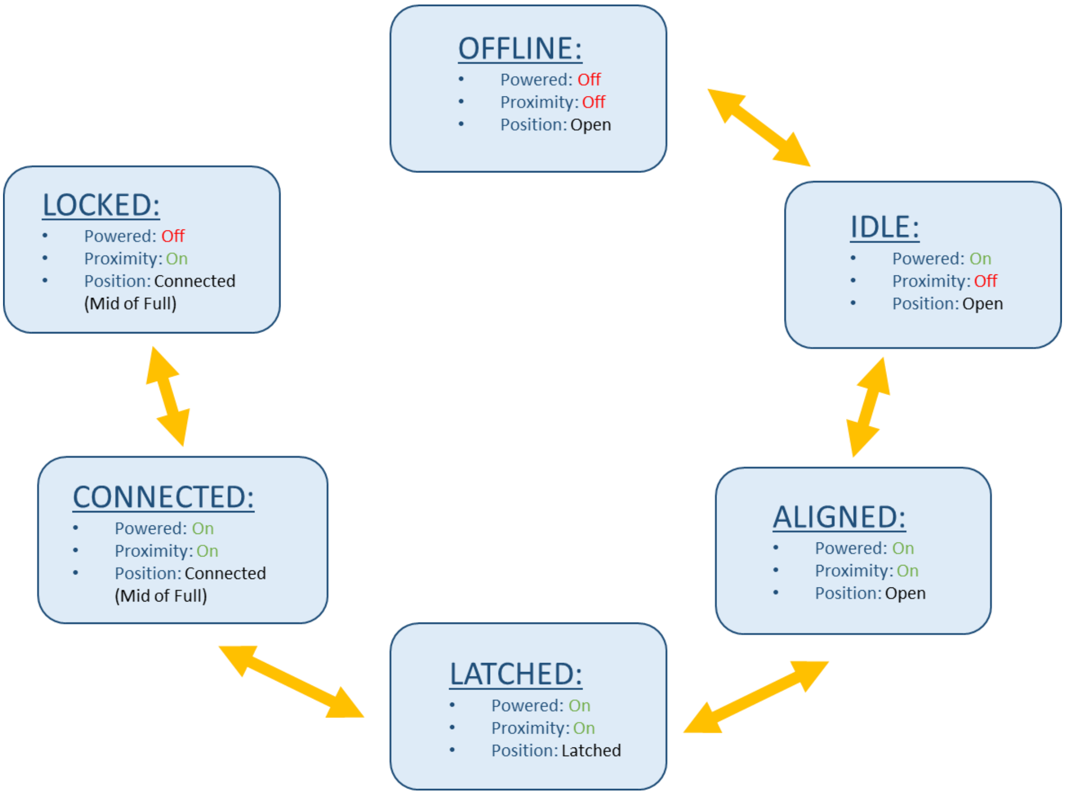


Figure 4-9: Nominal sequence of operation of HOTDOCK

The order to switch from the current (known) status to another is issued by an external authority (OBC, Ground, Spacecraft,…) through the usual CAN TMC "GoTo" telecommand (TC) packet, formed by the command itself and the expected new state as an additional parameter field (packet payload).

The new expected status can be the immediate next/previous state machine position, or a complete opposite position (e.g. typically from 'Mated' to 'Unmated'), thus implicitly traveling through intermediate state machine position without stopping.

Once a new expected position/status command is issued, the proper command itself is immediately acknowledged and the action (if achievable) is immediately processed.

While the command is actually performed, the external authority can have a near-to-Real Time visibility on the current position, expected position and motor monitoring through the intermediate House-Keeping (HK) telemetry (TM). Any error or unexpected result are also displayed in these TM packets.

The illustrations of the HOTDOCK mechanical configurations, measured by the absolute internal position sensor, are provided below, with the successive motion of the locking ring and the data/power/thermal connector plate (with mid or full extension).

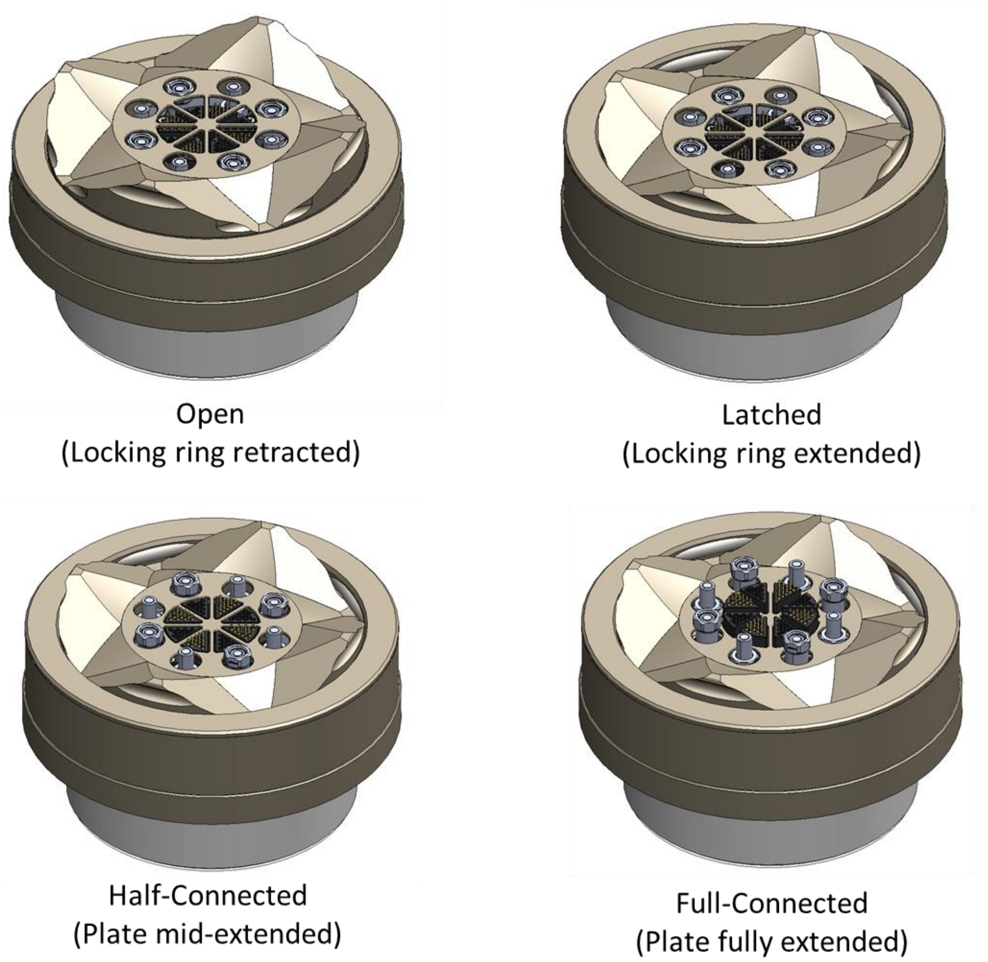


Figure 4-10: Mechanical configurations for the different operational states of HOTDOCK

4.2 Mechanical Interface and Actuation

The mechanical interface of HOTDOCK primarily is designed to allow mechanical coupling of two HOTDOCK interfaces and sub subsequently mechanical load transfer between both entities. In addition, it provides additional features as follows:

- **Androgynous Design**: The mechanical interface allows for coupling of two identical interfaces.
- **90 deg Symmetry**: The mechanical interface allows coupling all 90-degree of rotation, which is relevant in modular application but also providing more flexibility with robotic manipulation (in association with symmetric data/power interface, see section 4.3).
- **Form-Fit**: The front face geometry (s.c. FormFit) supports mechanical load transfer. In addition, this feature is essential to support positioning of two interfaces via external (e.g. robotic) manipulation and can compensate for misalignments.
- **High load capacity**: Due to the applied coupling mechanism high mechanical loads can be transferred.

Moreover, the mechanical interface is also supporting motion to guide and connect the thermal and electric connectors to fully couple two HOTDOCK interfaces.

In the following the general mechanical design will be described with focus on its coupling mechanism. In addition, the actuation system of HOTDOCK as well as the implemented sensors will be presented.

Figure 4-11: Mechanical Body of the HOTDOCK interface

4.2.1 Mechanical Design and Mechanisms

The mechanical design of HOTDOCK is done in a highly radial symmetric manner. This provides maximum packing density and subsequently reduces the needed volume by its internal components to a minimum. The main body parts are manufactured in high strain aluminium alloys which are nickel plated or anodized depending on part's function.

The coupling mechanism is using four Locking Pins which are embedded in the *Locking Ring* structure (Figure 4-12). To connect two HOTDOCKs the Locking ring is moving up and engages with the coupling partner by pressing its four *Locking Pins* into the *Locking Cavities* of the locking partner.

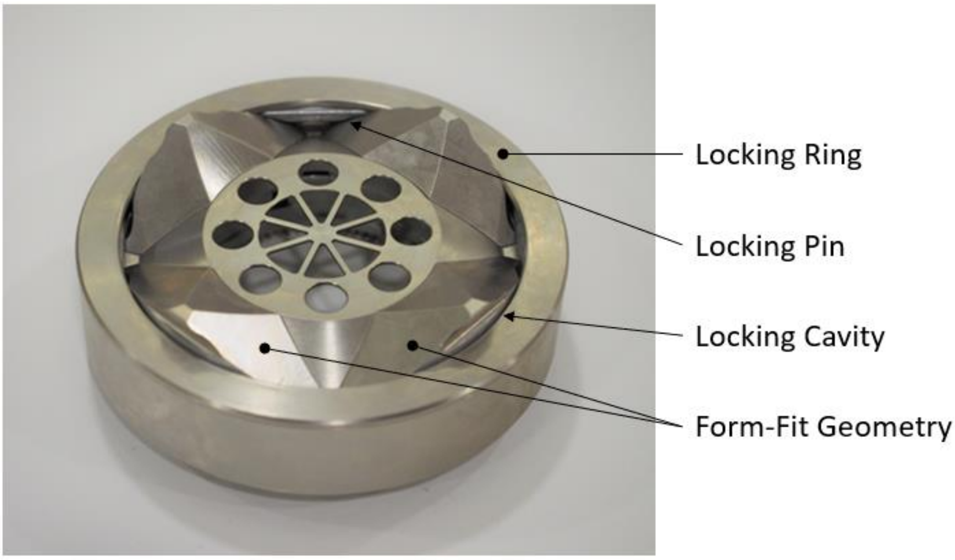


Figure 4-12: Main features of the locking mechanism.

The designed Form-Fit Geometry (Figure 4-12) supports a *Range of Attraction* of 15mm in radius. This means, as long as the off-axis-misalignment of an approaching HOTDOCK is smaller than 19mm, the Form-Fit Geometry will interact as passive guidance to centre well both coupling partner (under assumption of an adequate robotic compliance control).

Moreover, the Form-Fit Geometry's design allows for diagonal approach of a mating partner. The aperture angular of the approach corridor is 126 deg max. This characteristic of HOTDOCK allows for building lager structures by connecting simultaneously perpendicular (MOSAR) and hexagonal (PULSAR) components and by that is an essential feature of the HOTDOCK interface.

4.2.2 Actuation and Mechanism

The actuation of HOTDOCK is ensured via a brushless DC motor. The motor is connected to a gear box whose output drives a barrel cam. Cam follower mechanisms finally convert the rotational motion of the barrel cam into translational motions for driving the locking ring and the connector plate.

When actuating HOTDOCK, the design of the barrel cam ensures the sequence of motion as depicted in Figure 4-10 (or reverse by inverting the direction of rotation of the motor)

1. HOTDOCK is open (retracted docking ring)
2. HOTDOCK is closed (deployed docking ring)
3. Connectors are deployed (the stroke of the connectors can be selected to either reach an active or a passive HOTDOCK)

The time of operation for one HOTDOCK to go from the aligned to connected stated (locking ring latched + connecter plate connected) should be between 20s and 30s, as function of the final selection of the motor speed.

4.2.3 Sensors

The HOTDOCK interface is equipped with various sensors for proprioceptive status monitoring.

4.2.3.1 Proximity

For detecting the position of a mating partner the Form-Fit Geometry is equipped with a set of four Hall-Sensors as well as four magnets. Both, Hall-Sensors as well as magnets are embedded inside the Form-Fit Geometry, and by that, is greatly protected against mechanical impacts. The purpose of the Hall-sensors as well as the magnets is to track proximity to the mating partner as well as to detect the orientation of the mating partner. The measurement of the proximity enables to detect when the mating partner is in good position (inside acceptable misalignment range) to trigger the mating process. Sensing the orientation is required to perform adequate active pin mapping of the electric connectors to be correctly pre-set in respect to the actual rotation (90 degree symmetry) of the mating partner.

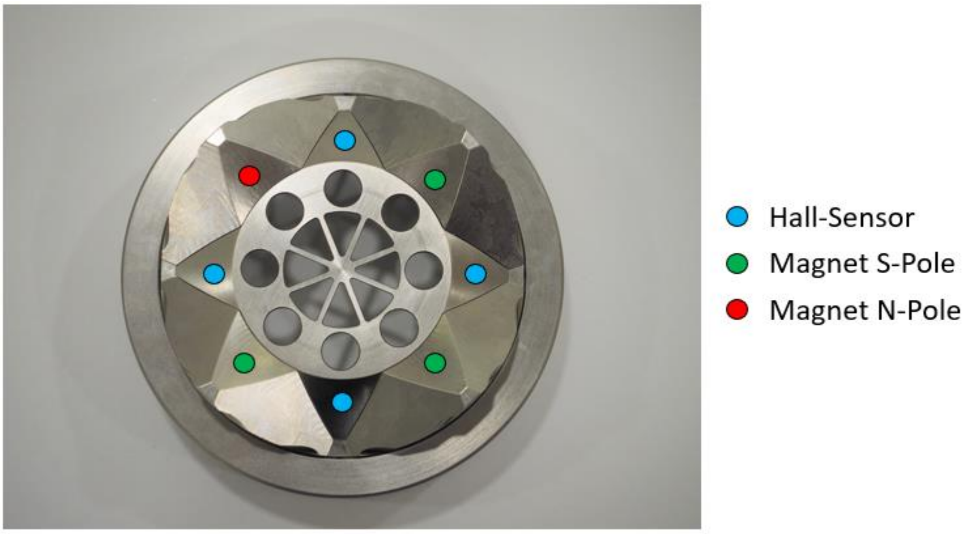


Figure 4-13: HOTDOCK Proximity Sensor Arrangement

To detect the orientation of the mating partner, one of the magnets is swapped in polarity which can be detected by the corresponding Hall-sensor. Still this sensor can measure the proximity to the magenta, same as the remaining sensors and it's corresponding magnets.

Detection of orientation works even if one of the four sensors (including the inverted one) is defect, as we still got the feedback from the three other ones (e.g. having only positive readings, tell us that the fourth is the negative, and potentially not working). Although this could be indicated as a status error, it allows performing the orientation detection and configuration of the data transfer. If more sensors are defected, we can remain on commanding and testing the data routing configuration, up to the point we get a communication.

The magnets are mounted in the four form-fit guiding pedals. This part can be un-mounted from the main body assembly and reconfigured to change the position of the "flipped" magnet if necessary (but not during operation).

4.2.3.2 Barrel Cam Position

In order to detect the position of the drive mechanism and the barrel CAM, and extract from it the mechanical state of the interface, an absolute hall position sensor is integrated at the rear of HOTDOCK, coupled with the gear mechanism. It provides a 1:1 position information to the controller.

4.2.3.3 Temperature

Four temperature sensors are embedded right at the same spot the hall sensors are positioned and by that close to the mechanical locking structure as well as equally distributed around the diameter of HOTDOCK. In addition, temperature sensors are placed at the motor, the thermal interface (hot and cold side) and on the main electronics.

4.2.4 Mechanical Performances

The following table summarizes the expected mechanical loading performances of HOTDOCK based on mechanical simulation analysis from the last version of the mechanical design (with 1.3 safety factor on components).

Table 4-1: HOTDOCK mechanical performances (simulation)

Axial Load	2000N
Bending moment	250Nm

4.3 Data and Power Interface

4.3.1 General Connector Plate Design

The HOTDOCK power and data interface are integrated in the inner section of the interface, through a connector plate. Both electrical power and data are transferred via a set of spring-loaded connectors also known as “POGO” connectors. They are particularly tolerant to misalignment and prevent accumulation of dirt or dust. This keeps the power and data transfer interface simple and subsequently improves its reliability. Each pin can transfer up to 3A of peak current (2A nominal). Dielectric separation distance between the POGO pins allows to transfer power with voltage up to 150V. The flexibility of connector layout makes it easy to integrate the POGOs in various patterns, as function of the application and the required power/data transfers.

At the core of the interface plate is a PCB which is split in four sections, each equipped with a set of pogo pins and pads. They are arranged in mirror to ensure the androgynous and 90 degrees symmetry characteristic of the interface.

The plate is translated through the same drive mechanism as the locking system. The barrel cam is configured to ensure the correct timing sequence for deployment.

Due to the different requirements for data and power transfer in MOSAR, PULSAR and PRO-ACT projects, two desings are foreseen for the interface plate: SpaceWire (MOSAR) and CAN/RS-485 (PULSAR/PRO-ACT). The main reason why a single consolidated design is impossible is because the MOSAR data interface has some specific challenges associated with high-speed signal routing and switching.

4.3.2 MOSAR – Space Wire Interface Plate

The SpaceWire variant contains 48 pins and 48 pads for transferring electrical power and data. In order to maintain the 100Ohm differential impedance of LVDS (SpaceWire) and allow a 90-degree androgynous connection, the design implements two 4x4 LVDS switches. In order to have this androgynous capability it is required to keep the cross point switch powered during data transmission.

The switches and routing of the signals are configured by the HOTDOCK controller, based on the detection of the HOTDOCK orientation, from the hall sensors.

The pinout of the interface plate for the SpaceWire variant is shown in Figure 4-14. The symmetrical layout achieves androgyny and provides the crossover that is required for the SpaceWire connection.

Sixteen power pins (8 power, 8 return) per quadrant allows for 2A x 8 x 4 = 64A current transfer through the plate. The maximum rated current is currently limited to 20A by the internal harnessing of HOTDOCK. Chassis connections added in case there is a need to equalise the chassis potential between two modules prior to transferring power and data.

Table 4-2 provides the power and data specifications of the SpaceWire variant of the connector plate.

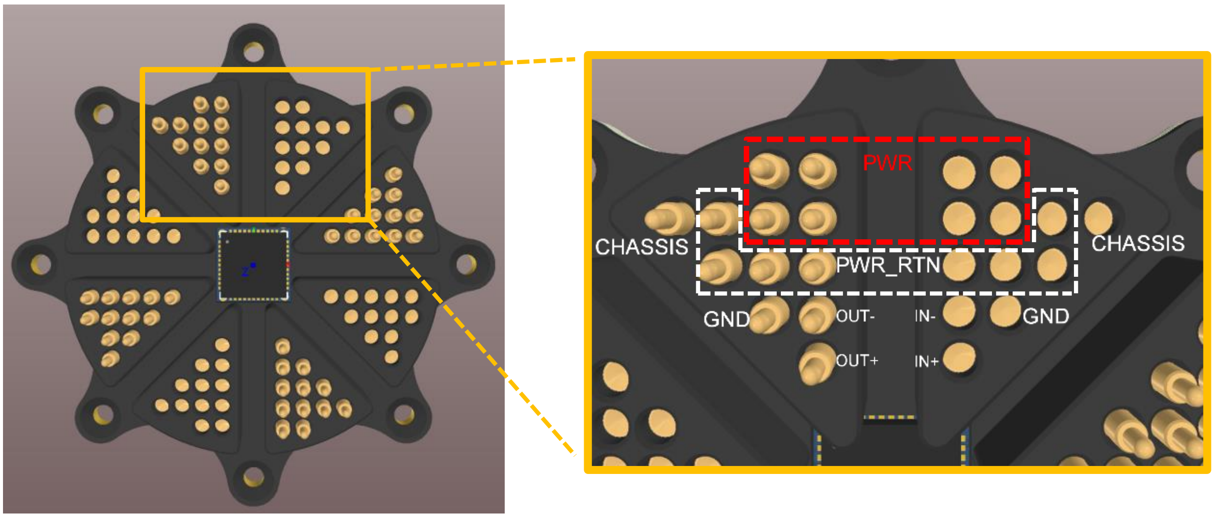


Figure 4-14: SpaceWire Interface Plate and Pinout

Table 4-2: SpaceWire Variant Power and Data Specifications

Parameter	Notes	Typ	Unit
Power Transfer			
Maximum voltage	With relay	120	V
	Without relay	135	V
Maximum current	With integrated relay	8	A
	Without relay	20	A
Resistance	Total resistance between two connected HOTDOCKs with relay on one side (active to passive connection)	40 (TBC)	mΩ
	Resistance without relay	30 (TBC)	mΩ
Number of pins	Power	32	
	Power return	32	
SpaceWire			
Wait	Time to wait before SpaceWire link is automatically active after HOTDOCK latching	TBC	ms
Maximum rate	Highest SpaceWire rate for nominal operation	200 (TBC)	Mbit/s
Insertion Loss	Insertion loss of a connected HOTDOCK pair at 100MHz Nyquist frequency (for a 200Mbps link)	TBC	dB

Note: All values include 10% of margin, compared to the specifications of the components.

4.3.3 PRO-ACT/PULSAR – CAN/RS485 Interface Plate

As the SpaceWire variant, the CAN/RS-485 version contains 48 pins and 48 pads for transferring electrical power and data. Due to similarities in physical layer of CAN and RS-485, the pins can be used for either application interchangeably, i.e. CANH and CANL can be replaced by RS-485 signal A and B.

Similar to the SpaceWire version, each quadrant of the interface plate contains a set of power and data pins. In order to allow androgyny and 90-degree symmetry, all CANH and CANL pins are locally connected. As a result, each interface plate has 8 connections for CANH (RS-485-A) and 8 connections for CANL (RS-485-B), resulting in great level of connection redundancy.

As with the SpaceWire version, the remaining pins are used for power transfer and an optional chassis connection. Sixteen power pins (8 power, 8 return) per quadrant allows for 2A x 8 x 4 = 64A current transfer through the plate. The maximum rated current is currently limited to 20A by the internal harnessing of HOTDOCK. Chassis connections added in case there is a need to equalise the chassis potential between two modules prior to transferring power and data. This connection, as well as the power is internally connected between the quadrants. Alternatively, the chassis pins can be used as an additional low power bus interface between two modules.

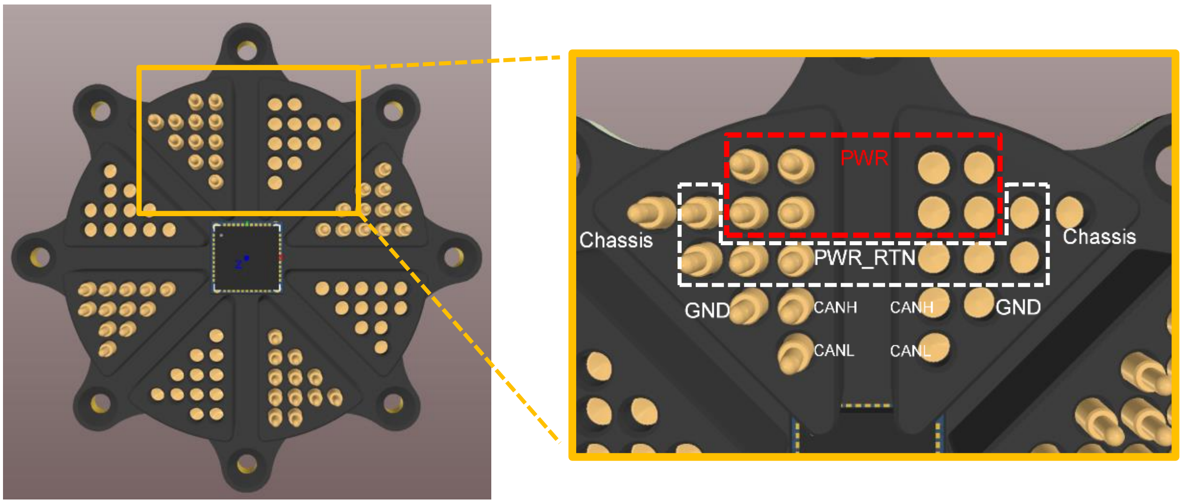


Figure 4-15: CAN/RS485 Interface Plate and Pinout

The following table provides the power and data specifications of the CAN/RS-485 variant of the connector plate.

Table 4-3: CAN/RS485 Variant Power and Data Specifications

Parameter	Notes	Typ	Unit
Power Transfer			
Maximum voltage	With relay	120	V
	Without relay	135	V
Maximum current	With relay	8	A
	Without relay	20	A
Resistance	Total power line resistance between two connected HOTDOCKs with relay	40 (TBC)	mΩ
	Resistance without a relay	30 (TBC)	mΩ
Number of pins	Power	32	
	Power return	32	
CAN			
Termination	120 Ohm termination resistor present on HOTDOCK transfer plate	No	
Wait	Time to wait before CAN link is automatically active after HOTDOCK latching	TBC	ms
Maximum rate	Highest CAN rate for nominal operation	200 (TBC)	Mbit/s
RS-485			
Wait	Time to wait before RS-485 link is automatically active after HOTDOCK latching	TBC	ms
Maximum rate	Highest RS-485 rate for nominal operation	TBC	Mbit/s

4.4 Thermal Interface

4.4.1 Geometry Definition

MOSAR Thermal IF consists of 8 hydraulic connectors (four males and four females) integrated in a 3D printed part made of stainless steel (see figure below.). The weight of the thermal IF is 143.5 g without hydraulic connectors and 181.6 g with connectors.

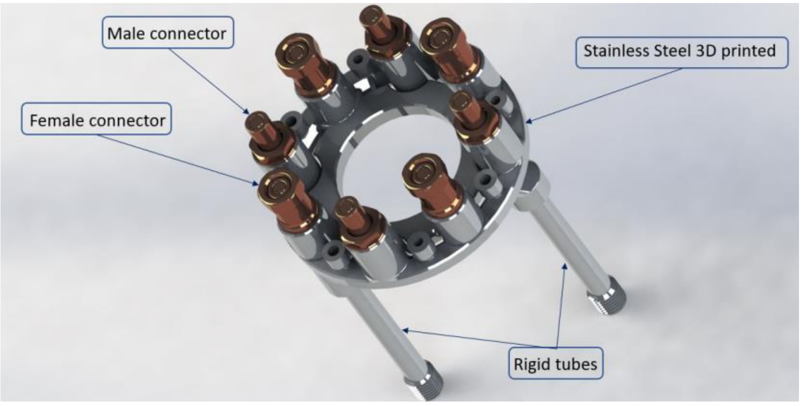


Figure 4-16: CAD model of Thermal IF

To get a tight tolerance in the 3D printed part, CNC machining will be required as a post-processing task. The tolerances required for precise positioning of the thermal IF with respect HOTDOCK are presented below.

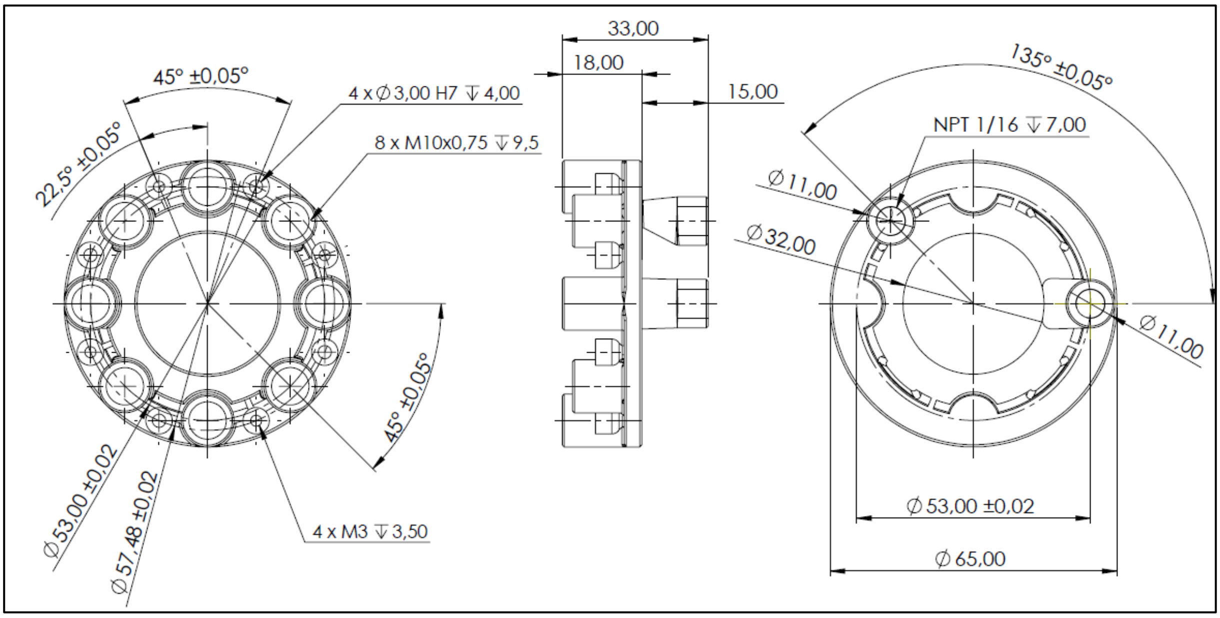


Figure 4-17: Thermal IF tolerances definition

Two stainless steel tubes are screwed into the back of the thermal IF and allow the liquid to move into the Spacecraft module. NPT 1/16 threads allow the screwed tubes to be sealed with respect the thermal IF. A detailed description of the link between tubes and thermal IF is depicted in the figure below.

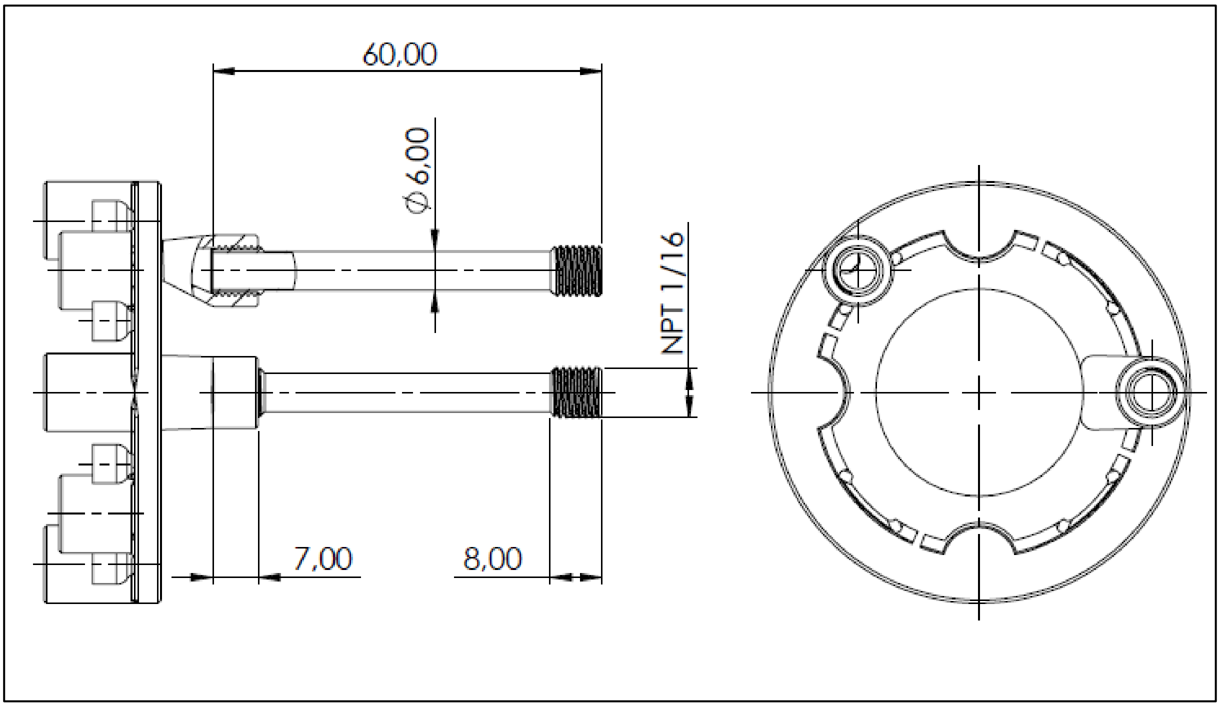


Figure 4-18: Thermal IF and rigid tubes connection

The main characteristics of the thermal IF developed by MAG SOAR are summarized in the table below:

Table 4-4: Main characteristics of Thermal IF

Parameter	Value	Unit
90-degree symmetry	-	-
Maximum heat exchange	2500	W
Operational Temperature range	-40 to 100	ºC
Maximum fluid flow	2.12	l/min
Maximum fluid pressure	15	bar
Minimum connection cycles	1000	-
Reference pressure drop	2	bar
Required connection force	400 ±10	N
Mass budget	0,181	kg
Heat exchanged between Cold and Hot line (+10ºC)	0.2	W

4.5 Dust Mitigation

The purpose of the dust mitigation strategies is to avoid internal contamination of the system (mechanisms, connectors, electronics,...) and ensure the correct mechanical connection and data/power transfer, despite the external conditions, for planetary applications. This topic can be very complex and highly demanding in terms of technologies, especially for the targeted applications on the Moon or Mars. For this reason, the detailed design of dust mitigation strategies for HOTDOCK is out of scope in this activity. However, this section describes the main approaches that could be envisaged, with their pros and cons.

By the design and its shape, the HOTDOCK device offers good initial protection against dust, especially once matted with another device. Also the POGO pin connectors of the data/power transfer plate are less sensitive to dust contamination. However, there are still openings to the internal mechanical and electrical components or with the front central connector plate. In the follow-up different strategies in terms of design or operations are described.

1. Environmental Sealing

Environmental sealing includes all techniques to seal openings in the design. The following picture illustrates the main areas that could be targeted to apply specific sealing. That includes

- The front side of the locking ring to improve the sealing when two devices are connected (no openings between two locking rings)
- The inner surface of the locking ring, to avoid internal contamination through the locking components
- The closing of gaps around the central (moving) connector plate

The main advantages of this strategy is the absence of moving components and additional mechanism, as well as keeping the full range of connector pins in the central plate. However, efficiency of the sealing needs to be ensured despite the interface with moving components and the aging of the sealing elements.

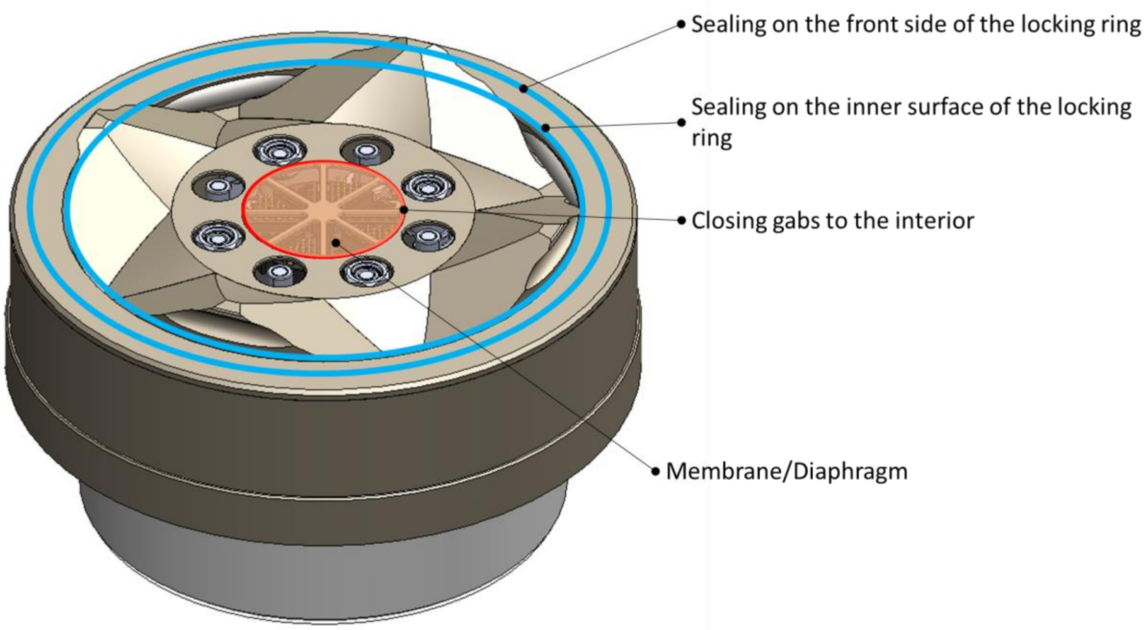


Figure 4-19: Dust mitigation strategies - Sealing and Membrane

An additional approach is to implement a penetrable membrane on top of the central connector, allowing the passage of the POGO pins, while protecting the connector when the device is not connected. As above, the main advantage is the absence of additional mechanisms, but the materials aging (polymers or soft material) could be a limiting factor. Also, to get full use of the connector plate surface, the moving plate (in case of an active/passive connection) should be equipped only with pins.

2. Shutters

An initial concept of dust protection with HOTDOCK, based on retractable shutters, has been proposed in the initial phase of the project. This concept is illustrated below.

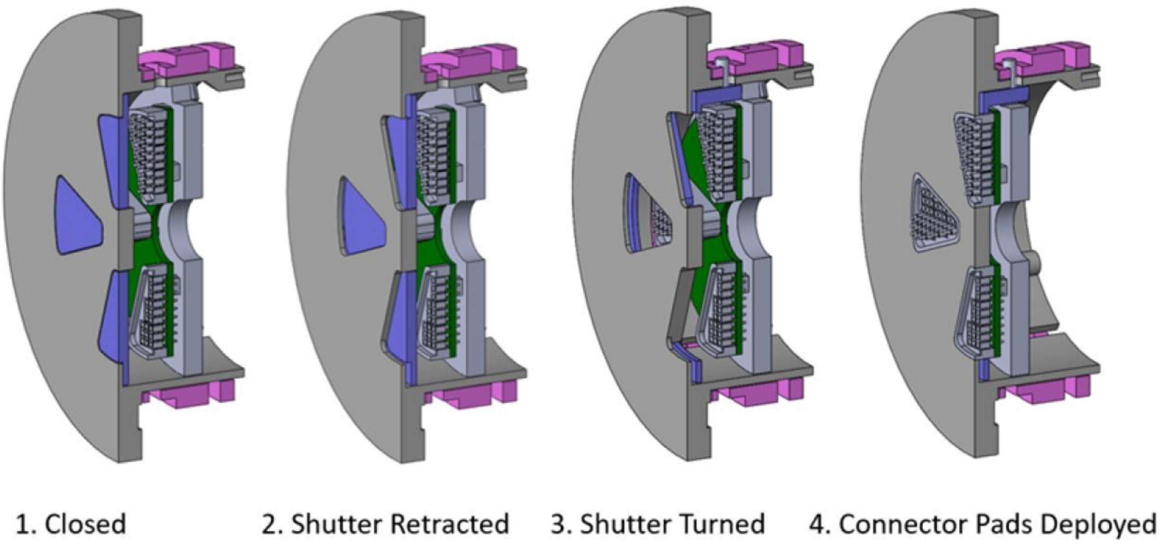


Figure 4-20: Initial dust mitigation concept by movable shutters

During the deployment procedure, the mechanism drives a double motion of shutters, with a successive translation and rotation, to free the path for the connector plate.

The advantage of this solution is the full protection of the central connector up to the point that both HOTDOCK are connected, after which the protection can be opened. The main disadvantage is the additional complexity of the internal mechanism that also needs to drive the motion of the shutters. Moreover, we need to take into consideration the management of the dust remaining on the surface of the shutters at the time of opening, that could then fall inside the system. It is also removing available area for the connectors.

3. Cover Lid

This solution is not directly associated with the design of HOTDOCK. Mainly for long duration exposure, it consists of covering the top plate with a passive element that would fully protect the system. It requires additional operation to remove the cover when we need to connect to the HOTDOCK. Elements are also exposed during the transition phase.

In practice we expect that an effective dust protection strategy should implement several of these concepts in order to offer the best possible protection.

4.6 HOTDOCK Controller

4.6.1 Controller Architecture

The main functional blocks of the HOTDOCK controller are depicted in the following figure.

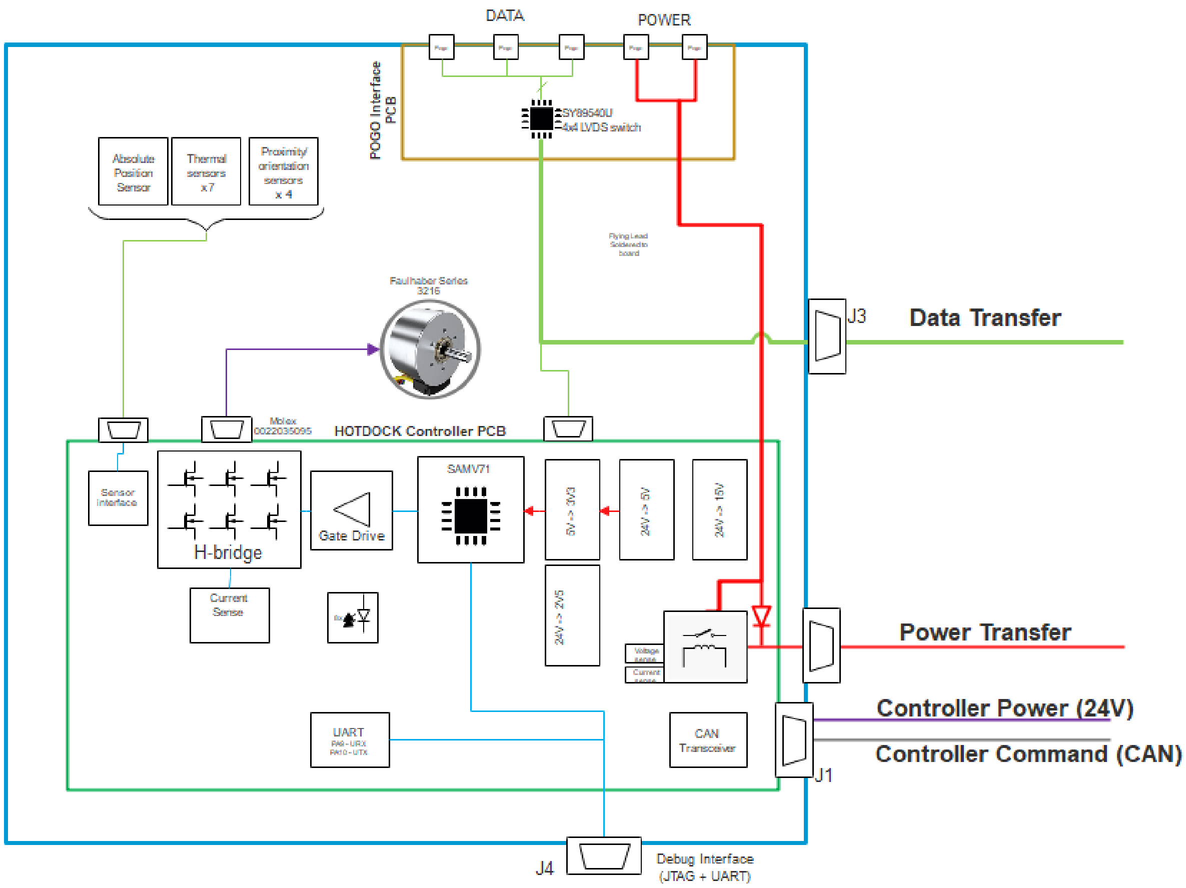


Figure 4-21: HOTDOCK Electrical Architecture (MOSAR variant)

As illustrated in the diagram, the controller is interfaced on one side (back connection) with the HOTDOCK control (CAN) /power (24V) lines and the power/data transfer lines. On the other side, it interfaces the POGO connector plate (front connection). The PCB controller is also equipped with an external interface to support update of the firmware and debugging during testing.

The HOTDOCK controller ensures the following functionalities:

- **Motor Control**: field oriented control of the brushless motor (motion of the locking system and connector plate), by interfacing a front-end chain (H-bridge, gate drive and buffer) through PMW signal.
- **Sensor Interface**: reading and processing analog internal signals of HOTDOCK including the hall effects proximity/orientation sensors, the absolute encoder locking sensor, the voltage/current of the power bus and the internal temperature sensors.
- **Connector plate Control** (for MOSAR): command the connector PCB LVDS switch to route signals according to HOTDOCK orientation.
- **TM/TC**: enables command and telemetry with an external OBC/EGSE through CAN bus.

- **Power relay control**: with an interface for a latching relay control (MOSFET based) to enable the bi-directional control of the power flow along the interface, up to 8A. For higher values, the relay drive circuit can also be used to drive external relay with higher current capabilities. Voltage and bidirectional current sense is implemented at the output of the relay (on the POGO pin side)

The HOTDOCK controller is implemented as a round-shaped custom PCB to seamlessly fit at the back of t the HOTDOCK mechanism.

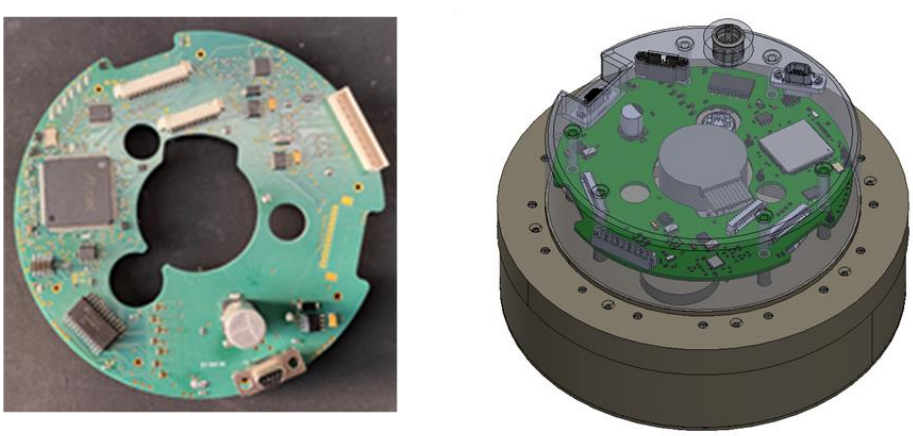


Figure 4-22: HOTDOCK Controller PCB

4.6.2 Electrical Characteristics

The following table provides the electrical characteristics of the HOTDOCK controller.

Table 4-5: HOTDOCK Controller Electrical Characteristics

Parameter	Notes	Typ	Unit
Power			
Supply Voltage	Input power for HOTDOCK TM/TC and actuation	24	V
Supply Current	Inrush – during power-up	380 (TBC)	mA
	Idle	145 (TBC)	mA
	During latching	265 (TBC)	mA
	Sleep mode	TBD	mA
Inrush time	Time it takes from power up for supply current to return to nominal value	TBD	ms
CAN			
CAN baud-rate	Bitrate of 500 kbit/s and Data bitrate of 2.000kbit/s	2	Mbit/s
CAN restart	CAN restart configured for 100 ms	100	ms
CAN bus load	Minimum load the CAN transceiver can drive	45	Ohms
CAN Sample Point	CAN Sample Point at 0.75	75	%
CAN Data Sample Point	CAN Data Sample Point at 0.75	75	%
CAN FD Support	Yes, auto negotiation.		
Termination	120 Ohm termination resistor present on HOTDOCK controller (can be removed on request)	Yes	N.A.
UART			
UART Baud-rate	115200	115200	Bps

UART Configuration	Asynchronous mode, with one start bit, eight data bits, and one stop bit.No HW/SW flow controls.	8N1	N.A.

4.7 Electrical Back Connectors

The back of the HOTDOCK device is equipped with connectors to interface it with the external systems. The following picture illustrates the current selection and placement of these connectors for the OGs projects (PRO-ACT, PULSAR and MOSAR). This selection, as well as their position can be updated or modified as function of the needs of the application and the available volume around the interface. The functions of the connectors are described in the table below.

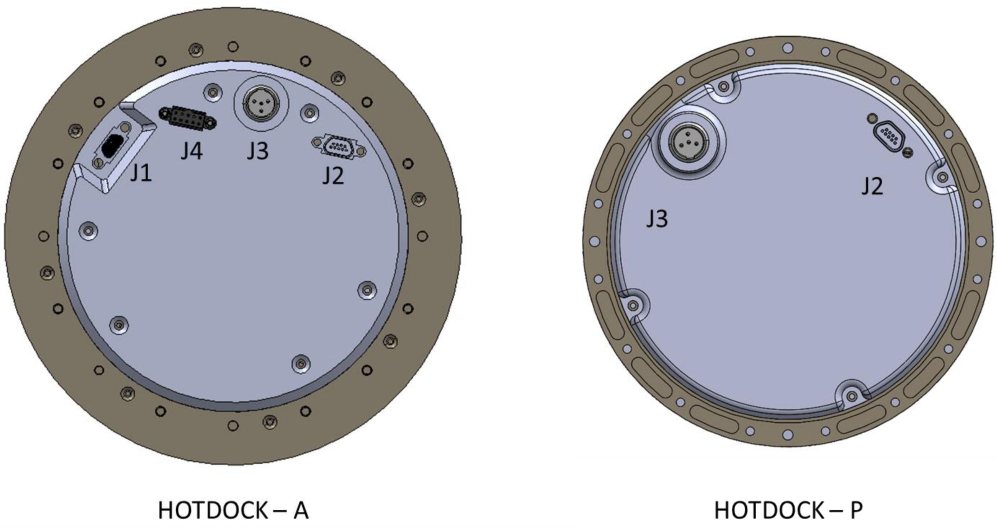


Figure 4-23: Active HOTDOCK Back Connectors

Table 4-6: HOTDOCK back connectors functions

Connector	Description
J1	HOTDOCK Control – CAN and power interface for controlling the HOTDOCK
J2	Data Transfer – Connection to the HOTDOCK interface plate
J3	Power Transfer – Connection to the HOTDOCK interface plate
J4	Debug Connector – JTAG and Serial interface for HOTDOCK controller

4.8 HOTDOCK Software, Communication and Control

4.8.1 HOTDOCK Firmware

The HOTDOCK firmware is responsible for the management of the HOTDDOCK controller PCB modules (motor, sensors, CAN transceivers, relays, LVDS switches, …) as well as the TM/TC with external components through CAN communication. It is composed of a single software running on the PCB microcontroller.

The HOTDOCK Firmware architecture is built around the following sub-systems (Classes), acting as different services with specific internal APIs and tasks:

- **CAN Service:** dealing with the CAN bus specific HW (transceiver) and is in charge of the proper reception and transmission of the CAN packets. This CAN service is interfaced to the TMC Engine through one RX Queue and one TX Queue for CAN Packets exchange.

- **TMC Engine:** processing and validating the received CAN Packet from the CAN RX Queue, acknowledging them and issuing the related local command. On request, it will prepare and publish the requested telemetry (TM) with appropriate House-Keeping (HK) data.

- **CMD Engine:** runs all the requested commands from the TMC Engine and update the data in the data pool of the On-Board Data Handler (OBDH)

- **OBDH:** maintains a local data pool updated with all external modules (sensors, motor, signals,..) parameters.

- **Analog Front End (AFE):** collect all required signals from external analog components and converting it into digital values (ADCs)

- **MOTOR Controller:** in charge of the motor driving the main Serial Interface mechanism.

4.8.2 HOTDOCK Communication Protocols

There is three means of communication with the HOTDOCK controller:

- CAN TM/TC: for standard communication and control with HOTDOCK (Connector J1)
- Serial Link: for debugging purpose (Connector J4)
- JTAG: for flashing the HOTDOCK controller in-situ (Connector J4)

4.8.2.1 CAN TM/TC

The communication protocol used to control HOTDOCK is the CAN bus. The can command should be provided by an external entity (e.g. EGSE, Ground, OBC, SpaceCraft, R-ICU,,…). HOTDOCK supports both regular CAN 2.0B and CAN FD protocols. Any HOTDOCK Serial Interface device can be directly interfaced with a local CAN bus and/or with a CAN port interface on a PC in order to control and monitor it.

If the data interface is also configured for CAN data transfer, a bridge between the control and transfer functionality could be envisaged, such that the HOTDOCK is on the same CAN bus than the payload components (e.g. for simple configuration with one interface and one payload)

The House-Keeping (HK) telemetry (TM) packet contains parameters stored in the internal On-Board Data Handler (OBDH) data pool. These parameters are reflecting the different status of the HOTDOCK controller, its external modules and sensors values. These values are grouped by theme in 5 main specific HK TM packets, as shown in Table 4-7:

Table 4-7: HOTDOCK House-Keeping (HK) TM Packets List

House Keeping (HK) - TM Packets				
HK TM Packet	Payload Size	Total Size	Max CAN Size	Description
HK1	42	50	64	Low Priority Parameters data
HK2	42	50	64	Main HOTDOCK Status data
HK3	56	64	64	HOTDOCK Temperatures data
HK4	48	56	64	HOTDOCK Interface & POGO data
HK5	44	52	64	HOTDOCK Motor data

The following tables provides the list of TMC codes.

Table 4-8: HOTDOCK TMC Codes – Packet Types List

CAN TMC Codes - Packet Types List			
Type Code	Dir.	Type Label	Description
TELECOMMAND	TC		
0x00	TC	TC_UNK	Unknown value (Unused)
0x01	TC	TC_HK1	HK1 Request
0x02	TC	TC_HK2	HK2 Request
0x03	TC	TC_HK3	HK3 Request
0x04	TC	TC_HK4	HK4 Request
0x05	TC	TC_GOT	Go to State +1 payload field
0x05	TC	TC_ATM	Auto TM [HZ] +1 payload field
TELEMETRY	TM		
0x80	TM	TM_UNK	Unknown value (Unused)
0x81	TM	TM_ACK	Acknoledged Pckt
0x82	TM	TM_NAK	Not Acknowledged Pckt
0x83	TM	TM_HK1	HK1 Response
0x84	TM	TM_HK2	HK2 Response
0x85	TM	TM_HK3	HK3 Response
0x86	TM	TM_HK4	HK4 Response

4.8.2.2 HOTDOCK Serial Link

When compiled with debugging support, the HOTDOCK firmware produces LOG information directly on its USART_1, which can be hooked to a serial link (over USB). This provide read-only information while the firmware is still running. The USART_1 are made accessible to the external world through J4 connector and these lines can be then hooked to a serial port and/or a USB converter in order to access the console log data from an external PC.

Note the console link is only used in order to provide debugging information support but will not provide in any case a way to command the HOTDOCK Serial Interface: the command of HOTDOCK is exclusively performed through the CAN Bus interface.

4.8.2.3 HOTDOCK JTAG

The JTAG interface will be exclusively used in order to flash the microcontroller in situ within the custom PCB. The JTAG lines are merged with the USART lines into the J4 connector.

4.8.3 HOTDOCK Coupling-Decoupling Sequence

The following tables provide a typical example of coupling and decoupling sequence of HOTDOCK, in the case of the connection between an Active (e.g. end-effector of a robotic manipulator) and a Passive (module interface) device, under the control of an external OBC. It provides the status of the involved sensors as well as the one feedback by the Controller to the OBC.

Table 4-9: HOTDOCK Coupling Sequence

Step	Action / Command	Powered	Proximity / Orientation	Absolute Sensor	HOTDOCK Status
0	Initial State: HOTDOCK powered off, decoupled	Off	N.A.	N.A.	N.A.
1	Power On HOTODCOK controller	On	Off	Open	Idle
2	Check CAN communication with HOTDOCK Controller with OBC				
3	Check HOTDOCK status is “Idle”				
4	Switch manipulator arm to impedance mode	On	Off	Open	Idle
4	Control manipulator arm to align both HOTDOCK	On	Off	Open	Idle
5	OBC receives “Aligned” state and stop alignment process of the manipulator	On	On	Open	Aligned
6	OBC sends TC TC_GOT (“Latched”)	On	On	Open	Aligned
	HOTDOCK actuator motion to extend the locking ring	On	On	Between Open and Latched	Aligned
7	Actuator motion stopped by absolute sensor in latched position (internal to HOTDOCK controller)	On	On	Latched	Latched
	OBC receives “Latched” state	On	On	Latched	Latched
8	HOTDOCK Controller detects relative HOTDOCK orientation	On	On	Latched	Latched
9	HOTDOCK Controller configures connector plate LVDS switches (for SpaceWire signals) – Not needed for CAN/RS-485 data transfer	On	On	Latched	Latched
10	OBC sends TC TC_GOT (“Connected”)	On	On	Latched	Latched
	HOTDOCK actuator motion to extract connector plate	On	On	Between Latched and Connected	Latched
11	Actuator motion stopped by absolute sensor in connected position (internal to HOTDOCK controller)	On	On	Connected	Connected
	OBC receives “Connected” state	On	On	Connected	Connected
	The data interface is operational	On	On	Connected	Connected
12	OBC sends TC TC_Power(“ON”) to enable power transfer through the power interface (if the internal HOTDOCK relay is used). The power interface is operational	On	On	Connected	Connected

Table 4-10: HOTDOCK Decoupling Sequence

Step	Action / Command	Powered	Proximity / Orientation	Absolute Sensor	HOTDOCK Status
0	Initial State: HOTDOCK powered on, connected	On	On	Connected	Connected
1	OBC sends TC TC_Power("OFF") to disable power transfer through the power interface (if the internal HOTDOCK relay is used)	On	On	Connected	Connected
2	OBC sends TC TC_GOT ("Latched")	On	On	Connected	Connected
	HOTDOCK actuator motion to retract connector plate	On	On	Between Connected and Latched	Connected
3	Actuator motion stopped by absolute sensor in latched position (internal to HOTDOCK controller)	On	On	Latched	Latched
	OBC receives "Latched" state	On	On	Latched	Latched
4	OBC sends TC TC_GOT ("Idle")	On	On	Latched	Latched
	HOTDOCK actuator motion to retract the locking ring	On	On	Between Latched and Open	Latched
5	Actuator motion stopped by absolute sensor in open position (internal to HOTDOCK controller)	On	On	Open	Aligned
	OBC receives "Aligned" state				
6	The OBC can control the manipulator arm to move HOTDOCK away	On	Off	Open	Aligned
7	Power Off HOTDOCK controller	Off	Off	N.A.	N.A.

5 HOTDOCK Requirements Compliance Analysis

5.1 General HOTDOCK Requirements

5.1.1 Functional Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Section Reference	Comment
FuncR_001	The standard interface shall provide a mechanical interface to couple spacecraft (active) modules with each other or to the spacecraft platform and bus respectively	M	1	ROD	Completed	2, 3, 4.2	
FuncR_002	The standard interface shall provide an electrical interface to transfer electrical energy (power)	M	1	ROD	Completed	2, 4.3	
FuncR_003	The standard interface shall provide a data interface to allow exchange of data between individual modules	M	1	ROD	Completed	2, 4.3	
FuncR_004	The standard interface shall provide a thermal interface to allow active transfer of thermal flow	M	1	ROD	Completed	2, 4.4	
FuncR_005	The standard interface shall allow the mechanical, power, data and thermal coupling with another interface that cannot provide actuation	M	1	ROD/T	Progress	2.2	To support faulty device and reduced interface functions (e.g. for cost reduction) Completed after tests
FuncR_006	The standard interface shall allow the mechanical, power, data and thermal de-coupling with another interface that cannot provide actuation	D	1	ROD/T	Descoped		To Support faulty device. Descoped since PDR

FuncR_007	The standard interface shall be compliant with launch loads	M	1	Analysis	Completed	RD1	Initial Analysis
FuncR_008	The mechanical interface shall withstand all mechanical loads brought by external sources to the interface during operations. The standard interface shall support the transfer of the following mechanical loads in connected configuration: • Axial Force: 400N • Radial Force: 400N • Bending Moment: 250Nm • Torsion: TBD Nm	M	1	Analysis/Test	Progress	4.2.4, RD1	Completed after tests
FuncR_009	The mechanical interface shall minimize force/torque for mating and de-mating	M	1	Test	Progress	RD1	
FuncR_010	The mechanical interface shall maximize positioning tolerance for mating, with a minimum of 5mm	M	1	Test	Completed	4.1.3.1	
FuncR_011	The standard interface shall be unlockable	M	2	Test	Descoped		The term unlockable is interpreted by the capability for two attached interfaces to unlock by the mean of a secondary mechanism, different from the standard actuation approach Descoped since PDR
FuncR_012	The standard interface shall be provide dust protection	M	1	ROD/T	Deviation	4.5	To support planetary applications Not implemented on physical device
FuncR_013	The power distribution unit shall provide low-level voltage power rails to supply the internals of the HOTDOCK interface – controller, sensors and motor drive.	M	1	ROD/T	Progress	4.6	
FuncR_014	The electrical interface unit shall be capable of supporting 1 kW of power transfer between two standard interfaces.	M	1	Test	Progress	4.3	

FuncR_015	The electrical interface shall incorporate an overcurrent, overvoltage and thermal protection.	M	1	ROD/T	Progress	4.3	
FuncR_016	The electrical interface shall not cause electro-magnetic interference in the modules being coupled which affects their functionality.	M	1	Test	Progress	4.3	
FuncR_017	The electrical interface shall incorporate a bidirectional power switch to control current flow at the interface.	M	1	Test	Progress	4.3	
FuncR_018	The electrical interface shall provide temperature, and power (voltage and current) telemetry from local (TBC) and global power buses	M	1	Test	Progress	4.2.3, 4.6	
FuncR_019	Electrical system in passive state shall draw less than 0.5 of quiescent power. (Controller switched off)	M	1	Test	Progress	4.6	
FuncR_020	The data interface shall allow a data rate of minimum 100Mbit/s	M	1	Test	Progress	4.3	
FuncR_021	The data interface shall provide duplex communication abilities	M	1	ROD	Completed	4.3	
FuncR_022	The data interface shall support Ethernet or EtherCAT bus	M	1	Test	Deviation	4.3	The current design supports SpaceWire and CAN/RS485. By design, there is no reason that Ethernet/EtherCAT are not supported
FuncR_023	The data interface shall support SpaceWire bus	M	1	Test	Progress	4.3	
FuncR_024	The data interface shall support at least one technology with capabilities of dynamic data bus re-configuration and routing	M	1	Test	Progress	4.3	Supporting SpaceWire
FuncR_025	The thermal interface shall allow a thermal flow rating of: 250 W .	M	1	Test	Progress	4.4, RD1	

FuncR_026	The thermal interface shall provide active regulation of thermal flow	M	1	Test	Descoped	4.4	Regulation of the thermal flow will be managed by external components (e.g. pumps and controllers)
FuncR_027	The interface controller shall be able to control the actuator and process the associated sensors	M	1	Test	Progress	4.6	
FuncR_028	The microcontroller shall convert required analog sensor signals to digital values and store them in internal memory.	M	1	Test	Progress	4.6	
FuncR_029	The microcontroller shall define and store the status of the HOTDOCK interface based on sensor data: • Alignment / proximity status • Temperature • Controller supply voltage • Controller current consumption • Connection status • Motor position • SI orientation (c.f. design symmetry)	M	1	Test	Progress	4.6	
FuncR_030	The interface controller shall be to send and receive TM/TC from the module/spacecraft/EGSE OBC	M	1	Test	Progress	4.6, 4.8	
FuncR_031	The interface controller shall be able to monitor the status of connection of the interface	M	1	Test	Progress	4.6, 4.8	

5.1.2 Design Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
DesR_001	The standard interface shall have an androgynous design	M	1	ROD	Completed	2, 4	
DesR_002	The standard interface shall have a scalable design	M	1	ROD	Completed	4	
DesR_003	The standard interface design shall feature one-failure-tolerance redundancy The mechanism should not have single point of failure components	M	1	ROD/T	Progress	4, RD1	This is applicable to the different sub-interfaces. Includes sensors, motors and electronic boards. If additional parts can't be included, then a proof of high design margins shall apply.
DesR_004	The standard interface design shall present a low complexity with minimization of moving parts	M	1	ROD	Completed	4	
DesR_005	The standard interface shall have a robust design	M	1	ROD	Completed	4	Mechanism design shall take into account worst-case combinations (including uncertainties) of: • Extreme operational and survival steady state • Transient temperature • Mechanism heat dissipation Temperature gradients across the assembly (differential expansion)
DesR_006	The standard interface shall present a 90deg. rotational symmetry	M	1	ROD	Completed	2, 4	

DesR_007	The standard interface shall allow diagonal engagement up to 65 deg	M	1	Test	Completed	4.1.3.2	
DesR_008	The standard interface shall provide guidance form-fit features	M	1	Test	Completed	4.1.3.2, 4.2.1	
DesR_009	The standard interface shall be designed from dissimilar materials in case metallic materials are used	D(S)	1	ROD	Progress	4.2.1, RD1	The implementation of this requirement in the context of this activity (non-space compatible device) needs to be confirmed, in regards to the additional costs. If not compliant, the design adaptation and material selection to reach a flight compatible design shall be described.
DesR_010	The standard interface controller shall be integrated within the mechanical housing	M	1	ROD	Completed	2, 4.6	
DesR_011	The electrical interface shall be integrated within the mechanical housing	M	1	ROD	Completed	2,4.3	
DesR_012	Mechanism shall be designed with a lubrication function (dry or liquid) at the contact surfaces which are in relative motion	M(S)	1	ROD	Completed	RD1	The sliding surface should have lubrication (liquid or solid) to prevent wear and particle contamination. Only space grade lubricants must be used.
DesR_013	The motorization assembly shall provide the minimum required torque for the worst lifetime conditions	M	1	Analysis	Completed	RD1	The final motorization torque shall incorporate the uncertainty factors
DesR_014	The interface shall incorporate the minimum design safety factors	M	1	Analysis	Completed	RD1	Model uncertainty, fatigue life, buckling safety factors against yield must be demonstrated
DesR_015	Peak hertzian contact stress shall below 93% of yield	M	1	Analysis	Completed	RD1	The model shall exhibit stress values smaller than 93% of the weakest material during operation
DesR_016	Dissimilar metals shall have galvanic compatibility	M	1	Analysis	Completed	RD1	Metal contact should prevent galvanic corrosion
DesR_017	Selected materials shall be cracked resistant	M	1	Analysis	Completed	RD1	The material of the interface shall have a high resistance to corrosion cracking

DesR_018	Materials shall be flame retardant	M(S)	1	Analysis	Completed	RD1	Low flammability materials for all components (harness, electronics, lubricants)
DesR_019	Materials shall have low outgassing and toxicity	M(S)	1	Analysis	Completed	RD1	All components (harness, electronics, lubricants)

5.1.3 Physical Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
PhysR_001	The standard interface shall be optimized regarding the mass	M	1	ROD/T	Completed	4.1	
PhysR_002	The standard interface shall be optimized regarding size and volume	M	1	ROD/T	Completed	4.1	
PhysR_003	The standard interface shall be optimized regarding size and volume	M	1	ROD/T	Completed	4.1	

5.1.4 Interface Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
IntR_001	The standard interface shall provide a mechanical connection to the module, spacecraft bus or robotic end-effector manipulator, compatible with the mechanical loads transferred through the interface.	M	1	ROD	Completed	4.1.4	
IntR_002	The standard interface shall provide internal harnessing to connect power and data buses from the module, spacecraft or robotic end-effector manipulator	M	1	ROD	Completed	4.6	
IntR_003	The standard interface shall implement required RCOS software components	M	1	ROD	Descoped		Descoed since SRR
IntR_004	The standard interface shall allow data and commands transfer to/from other RCOS components through standardized RCOS data types	M	1	ROD	Descoped		Descoed since SRR
IntR_005	The microcontroller shall provide command and telemetry of HOTDOCK interface to the APM/ASM computing unit.	M	1	Test	Progress	4.8	
IntR_006	The thermal interface shall enable thermal connection to the module structure	M	1	ROD	Completed	4.4	

5.1.5 Operational Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
OpR_001	The standard interface shall be compatible with robotic servicing operations	M	1	Test	Progress	2, 3	
OpR_002	The standard interface shall be reusable	M	1	Test	Progress	4	Our current assumption is that the number of required cycles should range between 100 and 1000 cycles (TBC)
OpR_003	The standard interface shall allow module connections without restriction on relative module orientation	M	1	Test	Progress	4	Related to androgynous and symmetry characteristics
OpR_004	The open/locked state shall be detectable	M	1	Test	Progress	4.2.3, 4.6	
OpR_005	Relative module orientation of the standard interface shall be detectable	M	1	Test	Progress	4.2.3, 4.6	
OpR_006	The standard interface shall be able to open and close multiple times (including data, power thermal connectors mating/demating) The standard interface shall allow 500 mating/demating cycles	M	1	Test	Progress	4	Our current assumption is that the number of required cycles should range between 100 and 1000 cycles (TBC)
OpR_007	The temperature of the interface shall be monitored	M	1	Test	Progress	4.2.3, 4.6	
OpR_008	The good alignment before starting the mating process shall be detectable.	M	1	Test	Progress	4.2.3, 4.6	
OpR_009	The standard interface controller shall be able to be switched on/off	D	1	Test	Progress	4.6	

OpR_010	The power consumption of the standard interface shall be minimized with a maximum of : • 0.5W in passive mode (controller switched off) • 2W in idle mode (controller switched on / motor off) • 10W in active mode (controller switched on / motor on)	M	1	Test	Progress	4.6, RD1	
OpR_011	The coupling time between two standard interfaces shall be minimized	M	1	Test	Progress	4.2.2, RD1	
OpR_012	The mechanism shall be maintenance free during storage and ground operation	M	1	Inspection	Progress		No maintenance or human intervention should be made during ground tests and operations

5.1.6 Environmental Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
EnvR_001	The standard interface shall withstand space environment conditions	M(S)	1	Test	Progress	-	No testing in the current activity under space conditions.
EnvR_002	The standard interface shall withstand operational environmental conditions	M(S)	1	Test	Progress	-	No testing in the current activity under space conditions.
EnvR_003	The standard interface shall withstand temperature range between -55 and 85 C.	M(S)	1	Analysis	Progress	-	As a first step towards space compatible design, this is the selected range of temperature to be supported by the interface for the current developments. The current activity doesn't foreseen verification by testing for this requirement.

5.1.7 Configuration Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
ConfR_001	The standard interface shall be declined in different configurations that are: • Active • Passive (not active behavior but can be couple and transmit data and power) • Mechanical (not active and can only be coupled)	M	1	ROD	Completed	2.2	This is mainly to support costs and volume/weight reduction in the ground demonstrators. This could also be applicable in future mission depending on specific mission characteristics.

5.1.8 Human Factors Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
HumR_001	Sharp edges, corners, uncovered holes bigger than 10 mm, uncovered slots shall not be present	M(S)	1	Inspection	Completed	4.1	Sharp edges, corners, uncovered holes bigger than 10 mm, uncovered slots shall not be present

5.2 OG's HOTDOCK Requirements

5.2.1 Common Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
HOTDOCK-IRD-COMMON -0010	The SI shall have an androgynous design, including mechanical, data and power interfaces	M	1	ROD	Completed	2, 4	
HOTDOCK-IRD-COMMON -0020	The standard interface shall provide guidance form-fit features	M	1	ROD	Completed	4.2.1	
HOTDOCK-IRD-COMMON -0030	The standard interface shall present a 90deg. rotational symmetry, including mechanical, data, power and thermal interface	M	1	ROD	Completed	4.2, 4.3	
HOTDOCK-IRD-COMMON -0040	The two SI shall be correctly aligned before starting their mating process and the information shall be confirmed to the OBC	M	1	Test	Progress	4.2.3.1, 4.6	
HOTDOCK-IRD-COMMON -0050	The connection process shall be monitored and the good connection of the SI shall be confirmed to the OBC.	M	1	Test	Progress	4.2.3.1, 4.6	
HOTDOCK-IRD-COMMON -0060	The SI design shall allow active, passive and mechanical configuration	M	1	ROD	Completed	2.2	
HOTDOCK-IRD-COMMON -0070	The design of the SI shall take into account optimization of the	M	1	ROD	Completed	4	

	manufacturing and integration costs						
HOTDOCK-IRD-COMMON -0080	The standard interface shall be optimized regarding its mass	M	1	ROD/T	Progress	4.1.2	
HOTDOCK-IRD-COMMON -0090	The standard interface shall be optimized regarding size and volume	M	1	ROD/T	Progress	4.1.2	
HOTDOCK-IRD-COMMON -0100	The power consumption of the standard interface shall be minimized	M	1	Test	Progress	4.6, RD1	
HOTDOCK-IRD-COMMON -0110	The SI shall provide • a mechanical interface to mechanically couple two system components • an electrical interface to transfer electrical energy (power) between two system components • a data interface to allow exchange of data between two system components	M	1	ROD	Completed	2, 4	
HOTDOCK-IRD-COMMON -0120	The SI shall allow the coupling and decoupling with another interface that cannot provide actuation	M	1	Test	Progress	2, 4	
HOTDOCK-IRD-COMMON-0130	The electrical interface shall incorporate a bidirectional power switch to control current flow at the interface.	M	1	ROD/T	Completed	4.3	

HOTDOCK-IRD-COMMON-0140	The SI shall measure and store the following local SI parameters: • Temperature (Power electronics if local, structure) • Alignment / proximity status • Locking status • SI orientation (in relation with design symmetry) • Data/Power interface status • Thermal interface status • Motor position (incremental or absolute) / Mechanism position (absolute) • Motor current • Controller supply voltage	M	1	Test	Progress	4.2.3, 4.6	
HOTDOCK-IRD-COMMON-0150	Each SI power transmission shall be protected against short-circuit and surge	M	1	Test	Progress	4.3	
HOTDOCK-IRD-COMMON-0160	The SI shall feature redundant data, power and control interface	M	1	ROD	Deviation	4.3	Redundant signals can be considered though re-distribution of the data/power interface pins. Not implemented in current projects.

5.2.2 PULSAR Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
PULSAR-TECHREQ-dPAMT-080	The SI weight shall be minimized	M	1	ROD/T	Progress	4.1.2	
PULSAR-TECHREQ-dPAMT-090	Active SI shall provide active locking feature with mechanical, data and power transmission capability	M	1	ROD	Completed	2, 4	
PULSAR-TECHREQ-dPAMT-100	Passive SI shall provide mechanical, data and power transmission capability	M	1	ROD	Completed	2, 4	
PULSAR-TECHREQ-dPAMT-110	Mechanical SI shall provide mechanical transmission capability	M	1	ROD	Completed	4.2	
PULSAR-TECHREQ-dPAMT-120	Dummy SI shall be visually equivalent to a mechanical SI	M	1	ROD	Completed	2	
PULSAR-TECHREQ-dPAMT-210	The SI shall feature and androgynous design	M	1	ROD	Completed	2, 4	
PULSAR-TECHREQ-dPAMT-220	The SI shall allow an approach angle of minimum 65 degrees	M	1	Test	Completed	4.1.3.2	The final design offers 63 degrees, above the minimum of 60 degrees (additional 5 degrees were kept as margin)
PULSAR-TECHREQ-dPAMT-230	The SI shall provide mechanical guidance	O	1	Test	Completed	4.2.1	
PULSAR-TECHREQ-dPAMT-240	The SI shall provide a 90deg design symmetry	O	1	ROD/T	Progress	4.2.1, 4.3	
PULSAR-TECHREQ-dPAMT-250	An active SI shall be able to detect and send to the OBC the confirmation of the good connection with another SI	M	1	Test	Progress	4.2.3, 4.6	

PULSAR-TECHREQ-dPAMT-260	The SI design shall allow active, passive and mechanical configuration	M	1	ROD	Completed	2	
PULSAR-TECHREQ-dPAMT-270	One mated active SI with an active/passive/mechanical interface shall able to withstand the following (combined) loads: 120 N, 60 Nm	M	1	Analysis/Test	Progress	4.2.4, RD1	
PULSAR-TECHREQ-dPAMT-290	Active and passive SI shall provide a power transfer interface	M	1	Test	Progress	4.3	
PULSAR-TECHREQ-dPAMT-300	The system shall be able to individually switch on/off each SI power interfaces	M	1	Test	Progress	4.3	
PULSAR-TECHREQ-dPAMT-310	Active and passive SI shall provide a RS-485 data transfer interface	M	1	Test	Progress	3, 4.3	
PULSAR-TECHREQ-dPAMT-320	The SI controller shall provide a CAN interface for the SI TM/TC	M	1	Test	Progress	3, 4.6	
PULSAR-TECHREQ-dPAMT-340	An active SI shall be able to detect and send to the OBC the confirmation of the good alignment with another SI	M	1	Test	Progress	4.6	
PULSAR-TECHREQ-dPAMT-400	The RAS shall provide a mechanical interface to fix an active SI as end-effector	M	1	ROD	Completed	4.1.4	
PULSAR-TECHREQ-dPAMT-440	SI shall be used to interconnect tiles together (including the base tile) and allow mechanical, data and power transfer	M	1	ROD/T	Completed	3, 4	
PULSAR-TECHREQ-dPAMT-490	The SI stiffness when mechanically mated shall be maximized	M	1	Analysis	Progress	RD1	
PULSAR-TECHREQ-dPAMT-500	An active SI shall be able to get a telecommand from the OBC to request new state	M	1	Test	Progress	4.6, 4.8	

PULSAR-TECHREQ-dPAMT-510	An active SI shall be able to get a telecommand from the OBC that triggers an emergency stop of the actuator	M	1	Test	Progress	4.6, 4.8	
PULSAR-TECHREQ-dPAMT-520	An active SI shall be able to measure SI thermistors and send to the OBC the values	M	1	Test	Progress	4.2.3, 4.6, 4.8	
PULSAR-TECHREQ-dPAMT-530	An active SI shall be able to measure SI motor position and send it to the OBC	M	1	Test	Progress	4.2.3, 4.6, 4.8	
PULSAR-TECHREQ-dPAMT-540	An active SI shall be able to measure the current and voltage on the power interface and send them to the OBC	M	1	Test	Progress	4.3, 4.8	
PULSAR-TECHREQ-dPAMT-550	An Active SI shall be able to send to the OBC the current state of the SI	M	1	Test	Progress	4.8	
PULSAR-TECHREQ-dPAMT-560	An Active SI shall be able to send to the OBC error status of the SI	M	1	Test	Progress	4.8	
PULSAR-TECHREQ-dPAMT-570	An active SI shall be able to send relevant CAN acknowledgement messages	M	1	Test	Progress	4.8	

5.2.3 MOSAR Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
HOTDOCK-IRD-MOSAR-0010	The standard interface shall provide a thermal interface to allow active transfer of thermal flow between two Spacecraft Modules	M	1	ROD/T	Progress	4.4	
HOTDOCK-IRD-MOSAR-0020	The data interface shall support at least one technology with capabilities of dynamic data bus re-configuration and routing	M	1	ROD/T	Progress	4.3	SpaceWire
HOTDOCK-IRD-MOSAR-0030	The mechanical interface shall withstand, in connected mode, all mechanical loads induced by the demonstration operations: • Axial Force: 250 / 160 N • Radial Force: 250 / 160 N • Bending Moment: 204 / 84 Nm As function of the gravity compensation of the SM (TBC).	M	1	Analysis/Test	Progress	4.2.4, RD1	
HOTDOCK-IRD-MOSAR-0040	The electrical interface shall be capable of supporting [1-2kW] (TBC) of power transfer, as required by the MOSAR demonstration	M	1	Test	Progress	4.3, RD1	
HOTDOCK-IRD-MOSAR-0050	The data interface shall allow a data rate of minimum 50Mbit/s	M	1	Test	Progress	4.3	

HOTDOCK-IRD-MOSAR-0060	The thermal interface shall allow a thermal flow rating of: 250 W	M	1	Test	Progress	4.4	
HOTDOCK-IRD-MOSAR-0070	The standard interface shall provide a mechanical connection to the modules, spacecraft bus or robotic base/end-effector manipulator, compatible with the mechanical loads transferred through the interface.	M	1	Analysis/Test	Progress	4.1.2.4	
HOTDOCK-IRD-MOSAR-0080	The standard interface shall provide internal harnessing to connect power, data and control buses from the module, spacecraft or robotic base/end-effector manipulator	M	1	ROD	Completed	4.3	
HOTDOCK-IRD-MOSAR-0090	The thermal interface shall enable thermal connection to the thermal module sub-system	M	1	ROD/T	Progress	4.4	
HOTDOCK-IRD-MOSAR-0100	The SI shall be interfaced with a Power Distribution Unit (PDU) to provide low-level voltage power rails to supply the internal components of the SI (controller, sensors and motor drives)	M	1	ROD/T	Progress	4.6	
HOTDOCK-IRD-MOSAR-0110	The SI shall be able to send/receive local TM/TC to/from the module or spacecraft OBC TM: See FuncR_D109 list TC: • Coupling / de-coupling (TBC for intermediate states) • Electrical power transfer on/off • Low-level control (TBC)	M	1	Test	Progress	4.2.3, 4.6	
HOTDOCK-IRD-MOSAR-0120	The standard interface shall allow diagonal engagement up to 55 deg	M	1	Test	Completed	4.1.3.2	

HOTDOCK-IRD-MOSAR-0130	The standard interface (or a part of it) shall be able to be switched off/on (behave as a passive plug), while ensuring data and power transfer.	D	1	Test	Devitation	4.4, 4.6	In the current design, the LVDS switch needs to be kept power-on during data transfer (not the case for CAN/RS-485 or only power transmission)
HOTDOCK-IRD-MOSAR-0140	The coupling time between two standard interfaces shall be minimized	M	1	Test	Progress	4.2.2, RD1	
HOTDOCK-IRD-MOSAR-0150	The SI shall be safe to be manipulated during integration within SM, WM or Spacecraft Buses. If there exist potential risks, they shall be well documented	M	1	Inspection	Progress	-	
HOTDOCK-IRD-MOSAR-0160	The standard interface shall be declined in different configurations that are: • Active • Passive (not active behavior but can be couple and transmit data and power) • Mechanical (not active and can only be coupled) • Thermal (including thermal interface connectors, either active or passive)	M	1	ROD	Completed	2	
HOTDOCK-IRD-MOSAR-0170	Active and passive SI shall provide a SPW data transfer interface	M	1	Test	Progress	4.3	

5.2.4 PRO-ACT Requirements

ID	Short Description (Refer to Requirement Document for complete)	Priority	Version	Verification	Status	Reference	Comment
HOTDOCK-IRD-PRO-ACT-0030	The HOTDOCK interface shall provide dust protection in connected mode	M	1	Inspection	Completed	4.5	
HOTDOCK-IRD-PRO-ACT-0040	The HOTDOCK interface shall support the transfer of TM/TC between the IBIS and the gripper (through CAN data interface).	M	1	Test	Progress	3, 4.3	
HOTDOCK-IRD-PRO-ACT-0050	The HOTDOCK interface shall support power transfer to operate the gripper (through the power interface).	M	1	Test	Progress	3, 4.3	
HOTDOCK-IRD-PRO-ACT-0060	The HOTDOCK interface shall support the transfer of TM/TC between the gantry OBC and the 3D printed head.	M	1	Test	Descoped	N.A.	
HOTDOCK-IRD-PRO-ACT-0070	The HOTDOCK interface shall support power transfer to operate the 3D printed head	M	1	Test	Descoped	N.A.	
HOTDOCK-IRD-PRO-ACT-0080	The HOTDOCK interface shall provide automatic confirmation of the connection status to support autonomous operations, as tool exchange	M	1	Test	Progress	4.2.3, 4.6	
HOTDOCK-IRD-PRO-ACT-0090	The HOTDOCK power interface could provide switching and monitoring capabilities	O	1	Test	Progress	4.3	

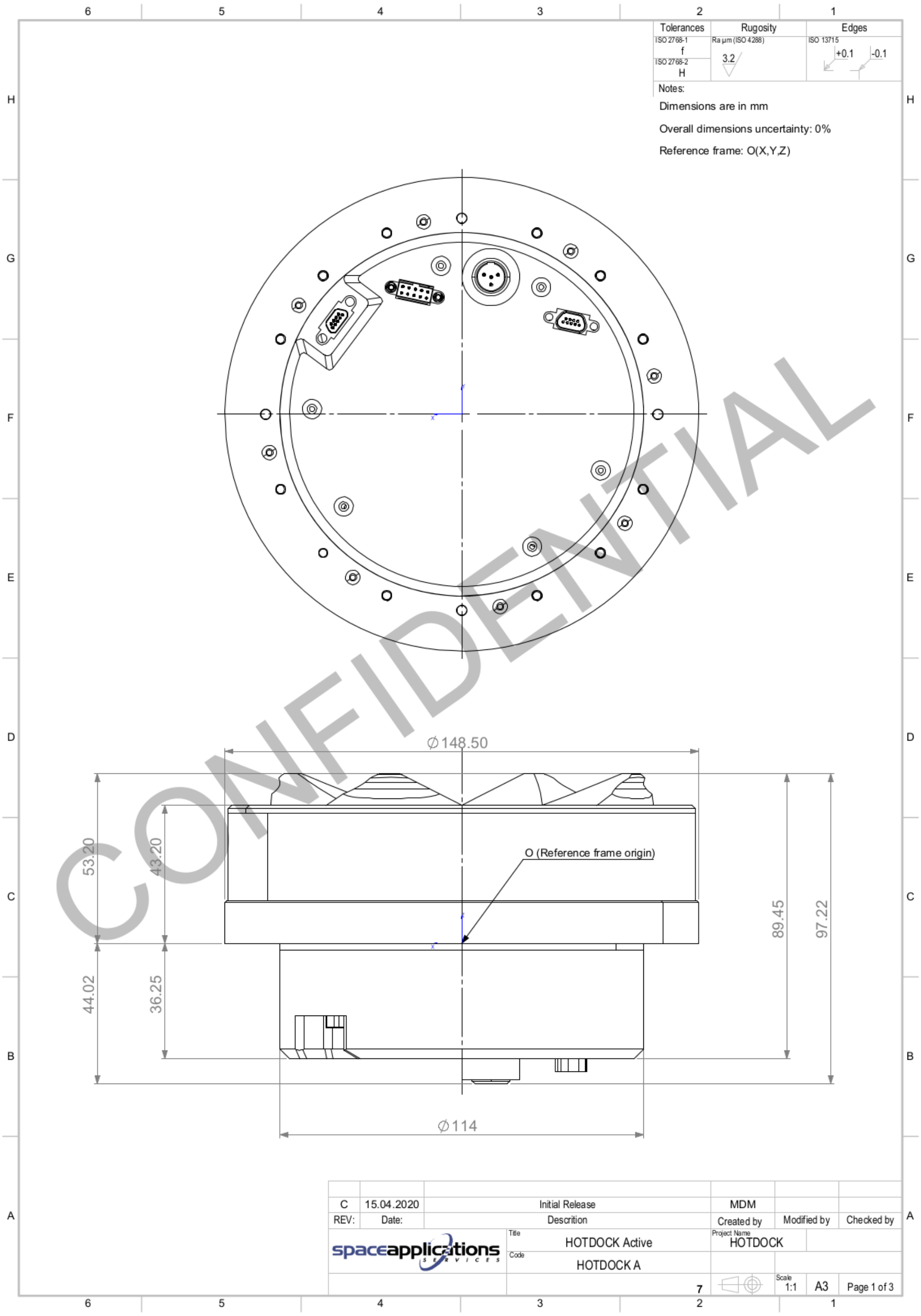
HOTDOCK-IRD-PRO-ACT-0100	Connected HOTDOCK interfaces shall support mechanical loading during PRO-ACT demonstrations scenarios: • Bucket granding: bucket weight, debris and ground reaction forces (initial estimation: 400N in longitudinal and transversal force, 120Nm, for 40kg pressure and 0.3m lever arm) • IBIS Gripper: gripper weight, lifted object and mechanical interaction forces • Payload: weight of the payload and interaction forces (with IBIS or gantry application) (initial estimation: 200N in longitudinal and transversal force, 100Nm in bending torque, for a box of 20kg, COG 0.5m) • Gantry 3D Head: weight of the 3D printing head in operating mode	M	1	Analysis/Test	Progress	4.2.4, RD1	
HOTDOCK-IRD-PRO-ACT-0180	The HOTDOCK interface should provide connection symmetry (mechanical and data interface) to simplify robotic operations	D	1	Test	Progress	4.2.1, 4.3	
HOTDOCK-IRD-PRO-ACT-0190	The HOTDOCK interface should allow diagonal engagement to relax constraint of RWA trajectory planning and precision requirements	D	1	Test	Progress	4.1.3.2	
HOTDOCK-IRD-PRO-ACT-0200	The HOTDOCK operations and TM shall be monitored and displayed to the operator.	D	1	Test	Progress	4.6, 4.8	

HOTDOCK-IRD-PRO-ACT-0210	The HOTDOCK interface shall be robust to mechanical interaction in disconnected mode	M	1	Inspection	Progress	4.2	

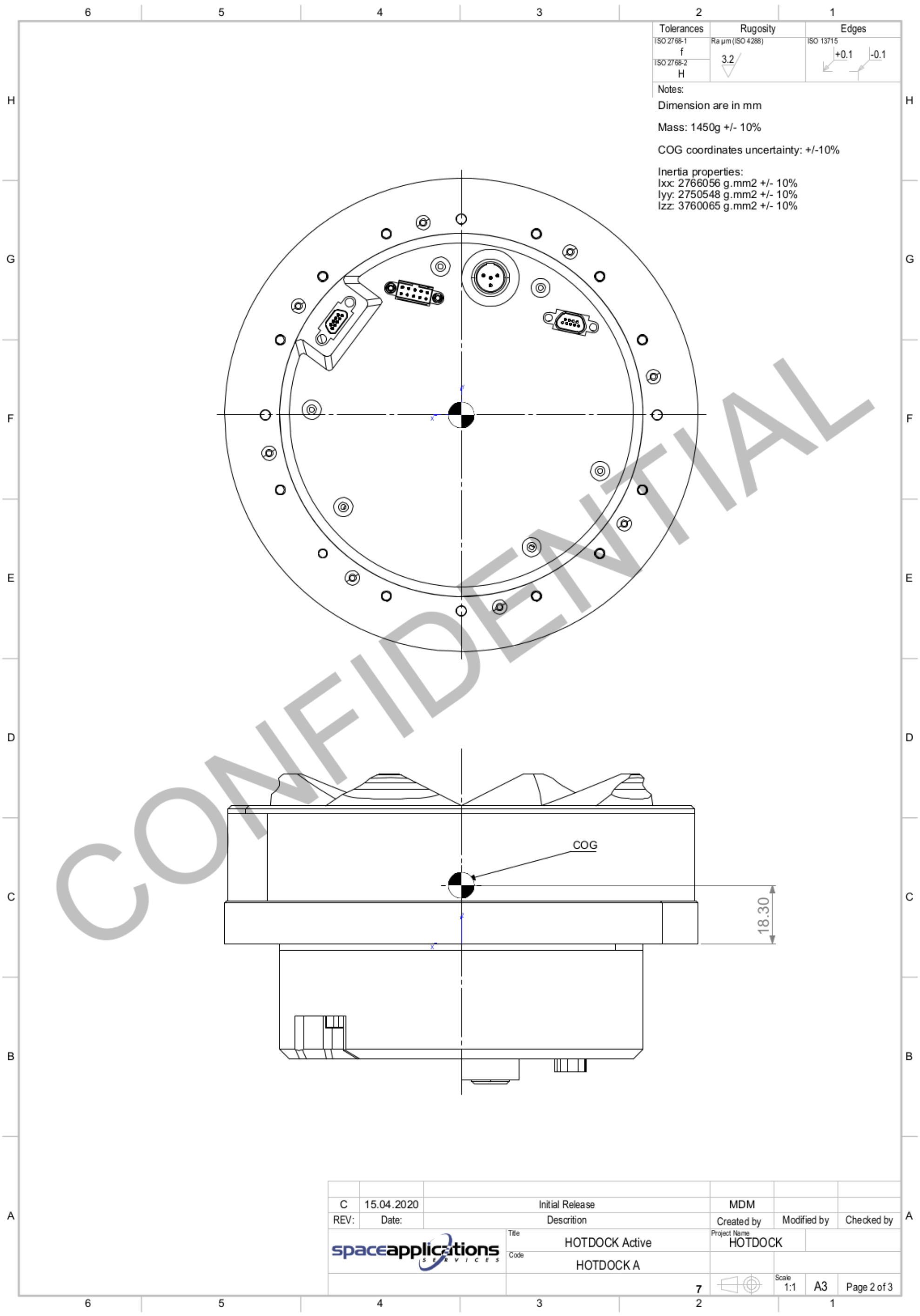
6 Reference Drawings

6.1 Active HOTDOCK

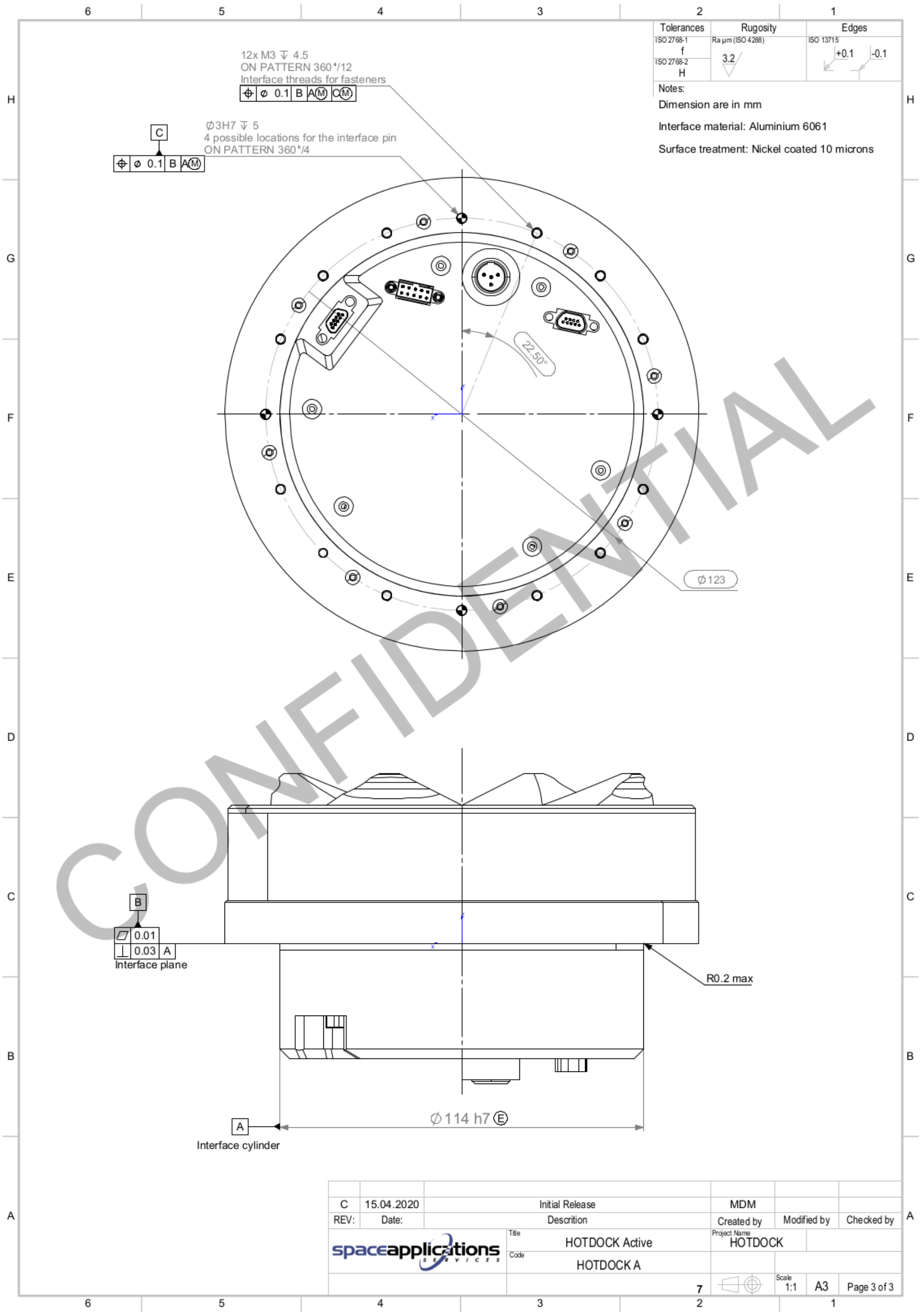
6.1.1 Overall Dimensions and Reference Frame Definition



6.1.2 Mass – Inertia – COG

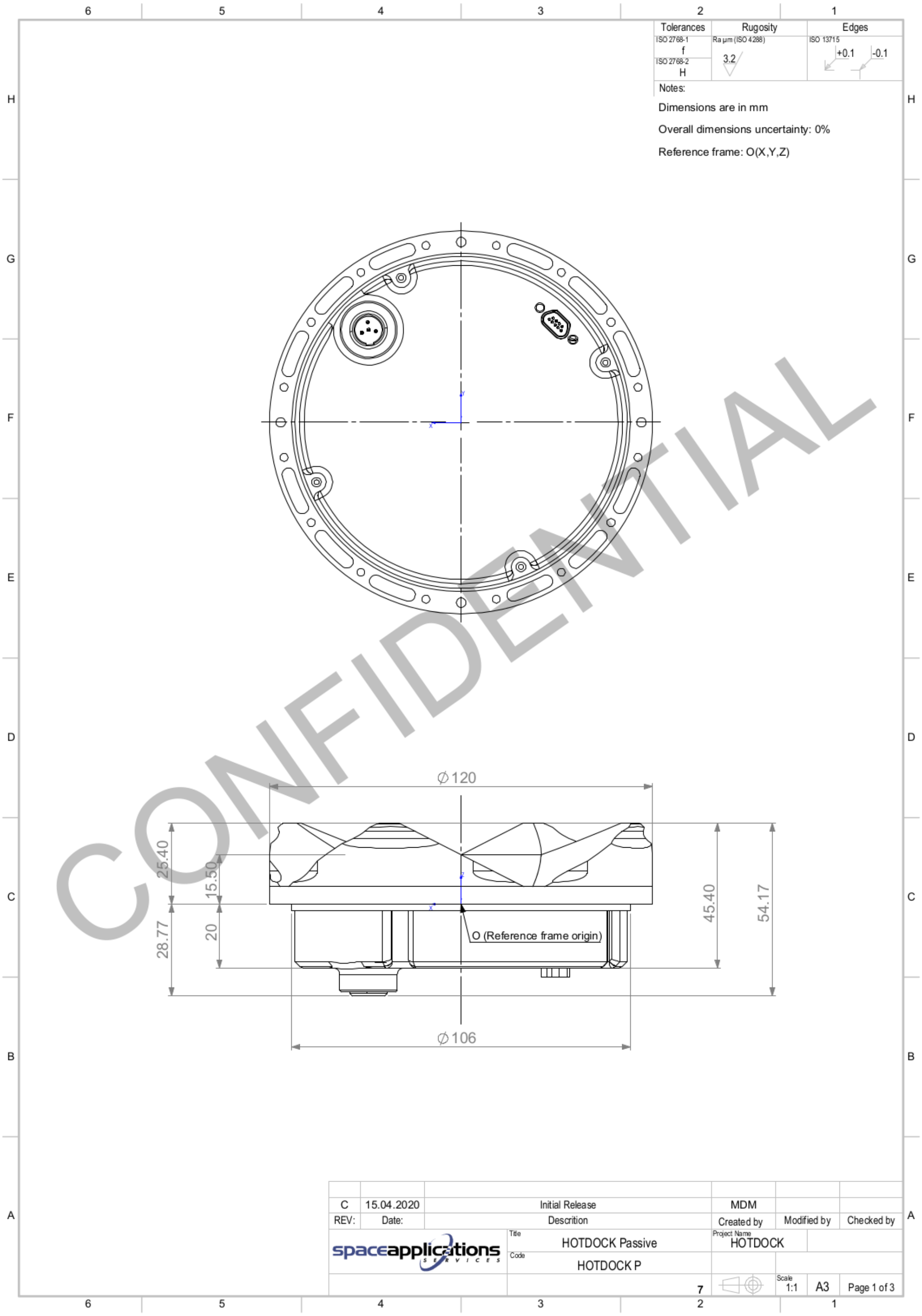


6.1.3 Mounting Reference and Interface Materials

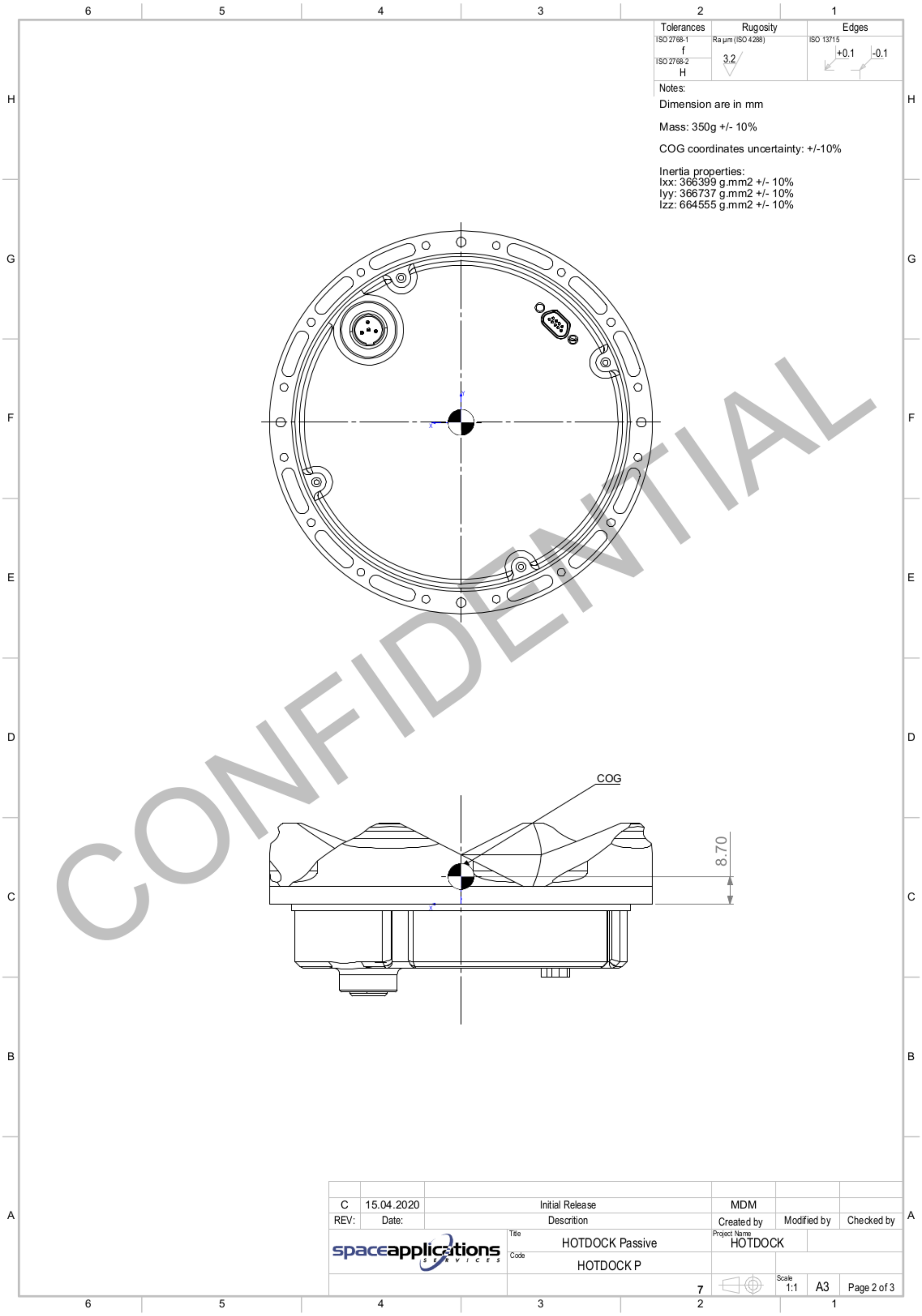


6.2 Passive / Mechanical HOTDOCK

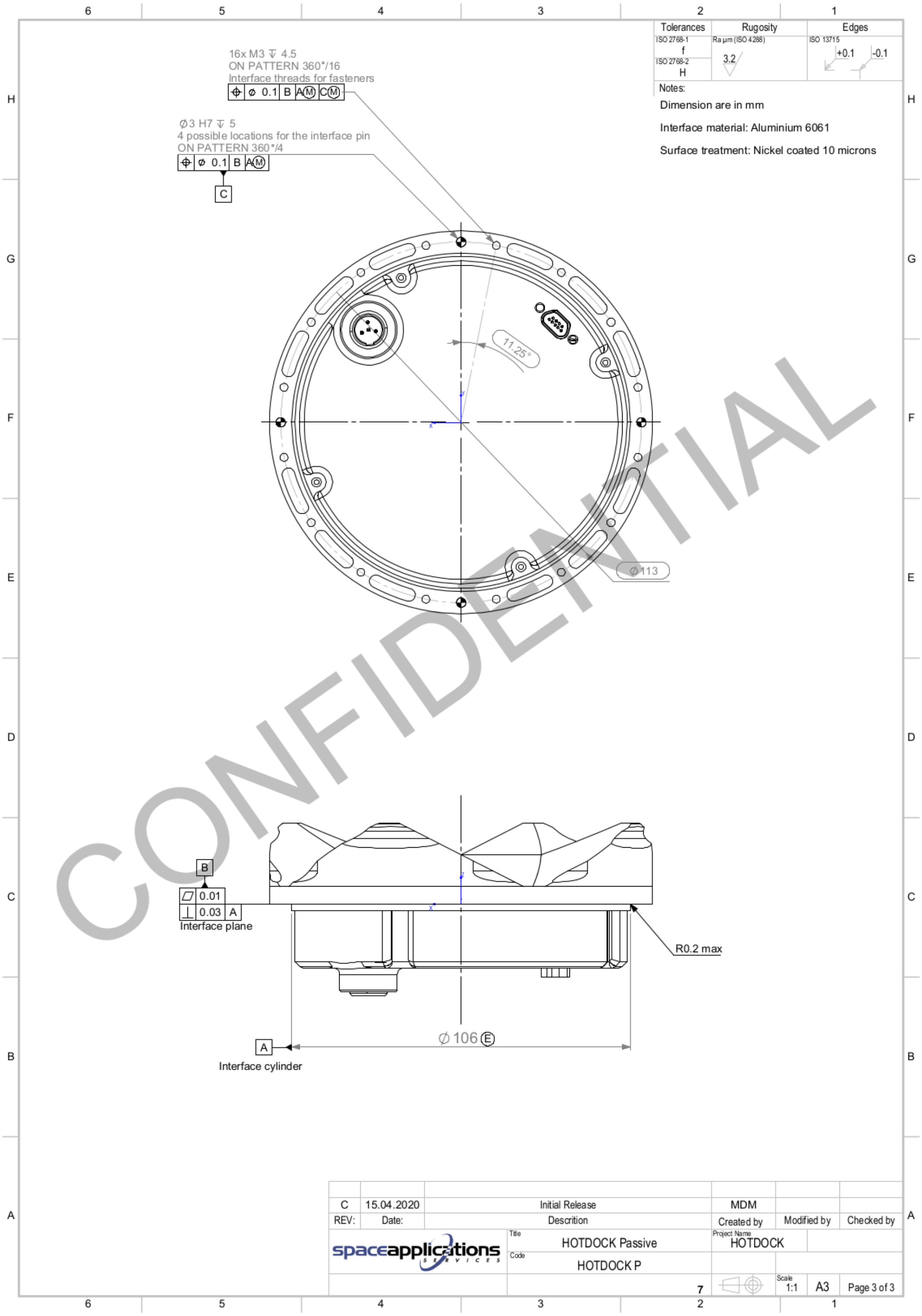
6.2.1 Overall Dimensions and Reference Frame Definition



6.2.2 Mass – Inertia – COG



6.2.3 Mounting Reference and Interface Materials



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