General overview of MORFEO (formerly known as MAORY) Instrument Control Hardware design

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ABSTRACT

This paper provides a description of the Instrument Control Hardware design for MORFEO (Multiconjugate adaptive Optics Relay For ELT Observations), an adaptive optics module for ESO ELT. The MORFEO Instrument Control Hardware is in charge of the control electronics of the entire system. The architecture of the control system is thus based on the paradigm of decentralized functions, connected via EtherCAT fieldbus, allowing for easy communication between components that are not physically near each other. The use of industrial standards and COTS elements also leads to rapid development, easier update of the components, lower cost for spare parts and a widespread understanding of architecture among specialized firms. The Instrument Control Hardware design described in this paper is an updated version of the configuration presented for the Preliminary Design Review in the first half of 2021.

Keywords: ESO, ELT, MORFEO, MAORY, PLC, EtherCAT, fieldbus

1. INTRODUCTION

MORFEO (Multiconjugate adaptive Optics Relay For ELT Observations) is a post-focal adaptive optics module, with the purpose of compensating for distortions caused by turbulence in the Earth's atmosphere [1]. MORFEO will be hosted on the Nasmyth platform of the ESO ELT (Extremely Large Telescope), in order to support the near-infrared camera MICADO and a second instrument yet to be defined [2][3]. The design of the MORFEO control electronics is shared between multiple work packages [4]. The subdivision of the electronics into subsystem is as follows:

- Main System
- Optomechanics
- Calibration Unit
- Deformable Mirrors
- Thermal Control
- Natural Guide Star (NGS) wavefront sensor module
- Laser Guide Star (LGS) wavefront sensor module

Ground-based and Airborne Instrumentation for Astronomy IX, edited by Christopher J. Evans, Julia J. Bryant, Kentaro Motohara, Proc. of SPIE Vol. 12184, 1218431

The division into subsystems allows for the independent design and testing of MORFEO functions, helping parallel development and simplifying the interfaces, which are based on the essential services [5].

The control electronics are responsible for the control of more than 30 axes and over 300 electrical functions. The electronics are distributed between nine cabinets.

This paper will focus on the preliminary design of the general Control Hardware architecture and of the Instrument Control Hardware Main System, which is in charge of the following functions:

- Power distribution to all subsystems
- Networks distribution
- General electronics design common to all (or most) subsystems
- Control electronics for Post Focal Relay Optics (PFRO) motorized functions
- Calibration Unit selector movement
- Internal illumination of MORFEO Main Support Structure
- Verification of compliance to ESO requirements
- Harmonization of the overall MORFEO control electronics design through the issue and update of design guidelines

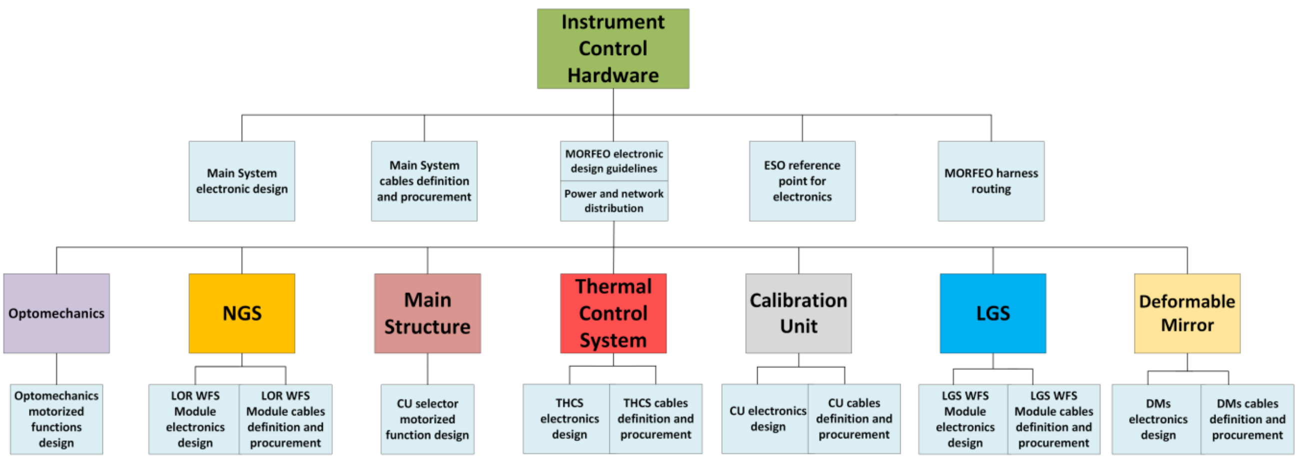

Figure 1. Diagram of MORFEO subsystems electronics design activities.

2. MORFEO INSTRUMENT CONTROL HARDWARE DESIGN OVERVIEW

The architecture of the control system is based on the paradigm of decentralized functions and the extensive use of field buses, drawing on industrial standards.

The MORFEO control electronics are managed by a single PLC, that is part of the Main System. This way, all MORFEO electronics operate under the same network, allowing for easy and quick communication among subsystems. EtherCAT fieldbus is largely employed for this purpose. Each sub-system has dedicated cabinets, or cabinet volumes, and PLC terminals, in order to facilitate the independent integration and verification for every sub-system. The use of industrial standards and COTS elements allows for rapid development, lower cost for spare parts and a widespread understanding of architecture among specialized firms.

Figure 2 offers an overview of ICH and the various subsystems cabinets. Due to the limited volume that is available on the Nasmyth platform, all the cabinets are placed on an intermediate platform, 7 meters below the Nasmyth, with the following exceptions:

- NGS WFS module cabinets, that are on the MICADO co-rotating platform.
- Post Focal Relay Optics cabinet, placed under the MICADO-MORFEO thermal duct support structure, on the Nasmyth platform.
- A smaller cabinet (Proximity Electronics Cabinet), placed on the Nasmyth platform, near the LGS WFS module, hosting electronics for the LGS module with critical cable lengths.

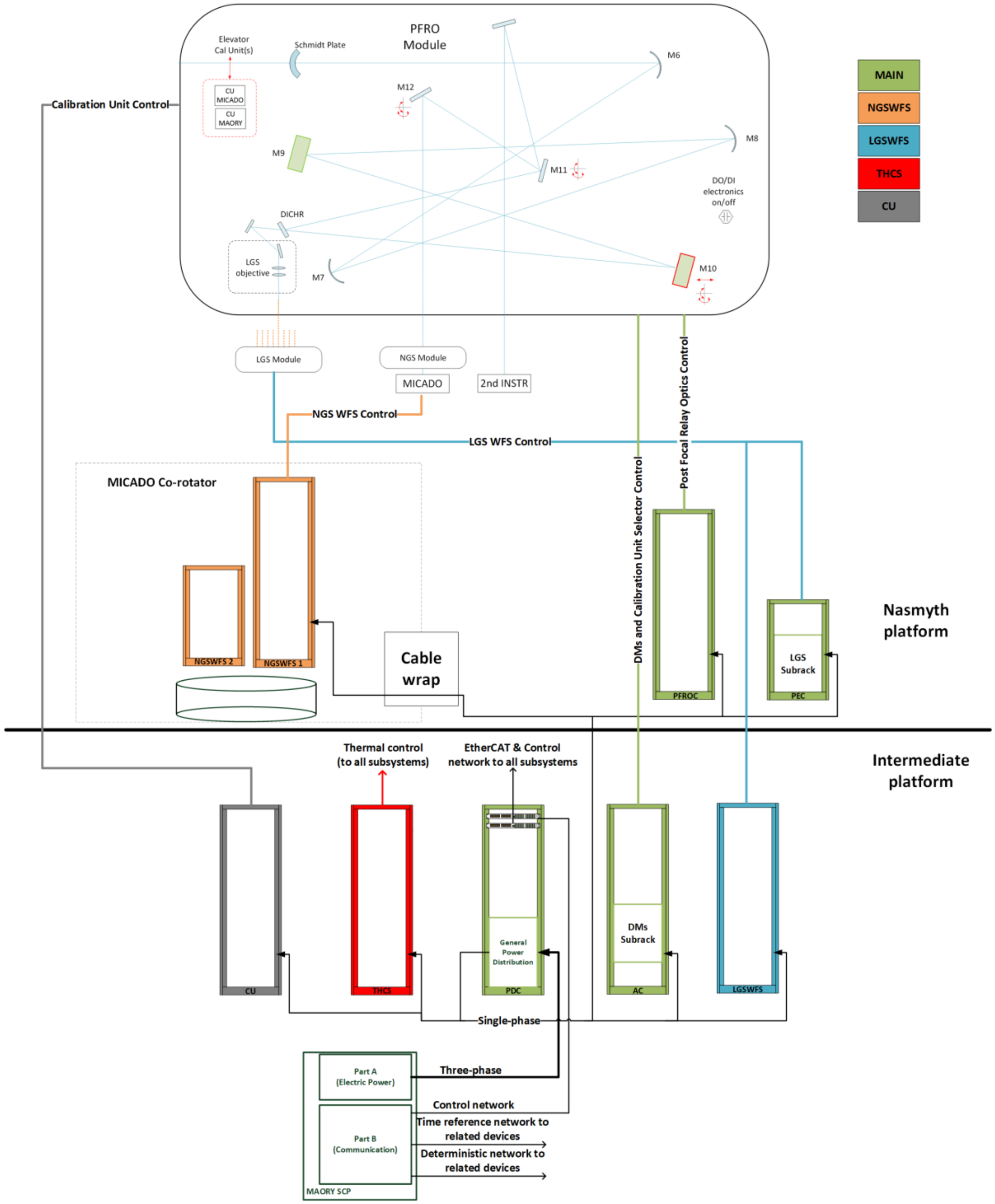

Figure 2. MORFEO Instrument Control Hardware Overview, colour coded for each subsystem cabinets.

In Figure 2, the Main System cabinets are shown in green. Their layout will be described in Section 3 of this paper.

2.1 Power distribution

MORFEO Instrument Control Hardware receives power from the MORFEO Service Connection Point.

More specifically, three-phase power is delivered to the Main System Power Distribution Cabinet (PDC). From there, the PDC provides single-phase power to all other electronic cabinets. The choice of having the PDC receive three-phase power from the SCP is made in order to ensure an effective balancing of the loads. In the current design, the loads are distributed as follows:

- The Power Distribution cabinet electronic devices and the Accessory and CU cabinet receive single-phase power from L1.
- The NGS and Thermal Control cabinets receive power from L2.
- The Post Focal Relay Optics, LGS and Proximity Electronics cabinets receive power from L3.

The three-phase power is monitored by a dedicated PLC terminal, that measures the voltage of the network and the current of the three phases via current transformers. It also provides the values of the effective power, the energy consumption and the power factor for each phase.

Each subsystem distribution is preceded by an inrush current limiter and a residual current device with overprotection. Furthermore, as shown in Figure 3, each load is also preceded by a contactor that can switch on and off the power supplied to the corresponding subsystem.

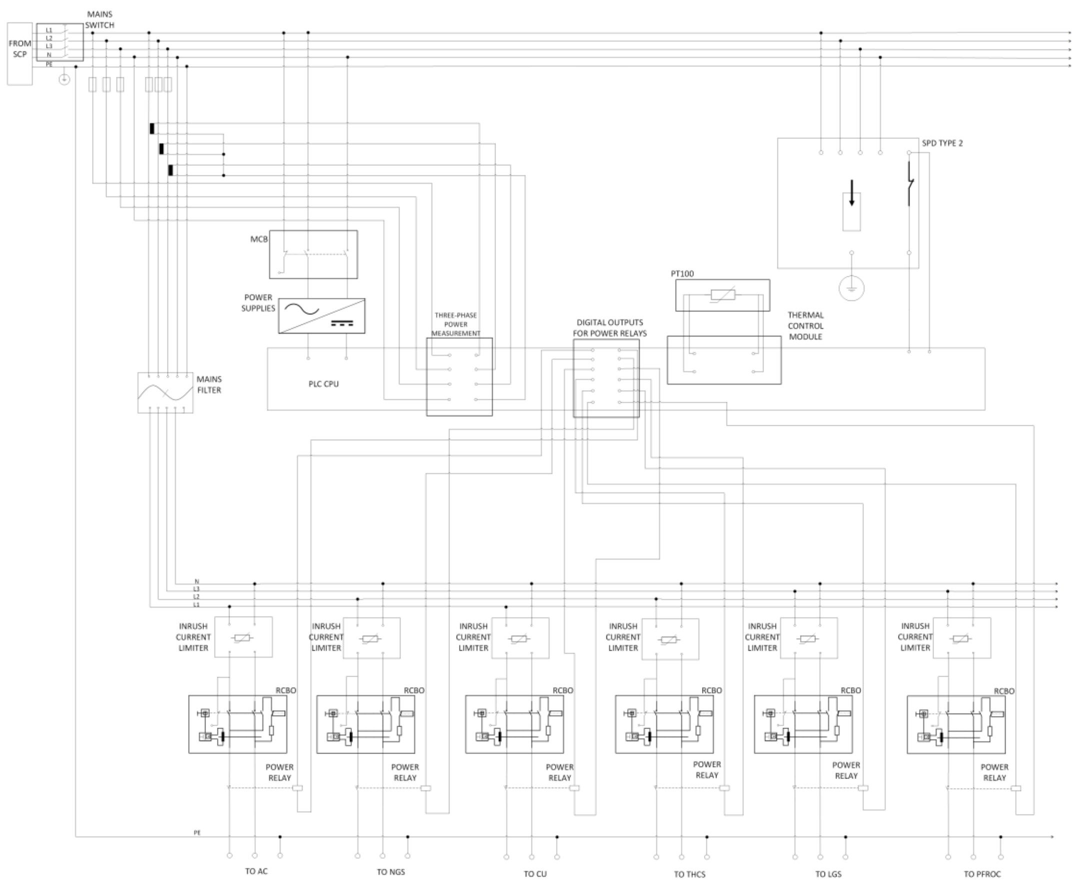

Figure 3. Three-phase power distribution scheme.

Single-phase power distribution inside each cabinet follows a similar scheme.

2.2 Networks distribution

Four main networks need to be distributed to the MORFEO control system:

- Control network
- Time Reference network
- Deterministic network
- EtherCAT network

Control network is provided from the SCP to the Main System, and specifically the Power Distribution cabinet, where an Ethernet switch is located. From the switch Ethernet connection branches off to each subsystem. One physical copper connection to the Control network is provided to each cabinet; a second switch inside the subsystem cabinet is required for connection to multiple devices inside the same cabinet.

EtherCAT connection is distributed downstream of the single PLC, through an EtherCAT hub located in the Power Distribution Cabinet. Starting from the hub, an EtherCAT cable reaches each cabinet, where it is connected to an EtherCAT coupler. The subsystem PLC terminals are then connected to the EtherCAT network through E-bus.

In case other EtherCAT devices are employed outside of the cabinets, they also will be connected through EtherCAT to the rest of the system.

The subsystems are thus all connected to the same network in a star-like topology, as shown in Figure 4.

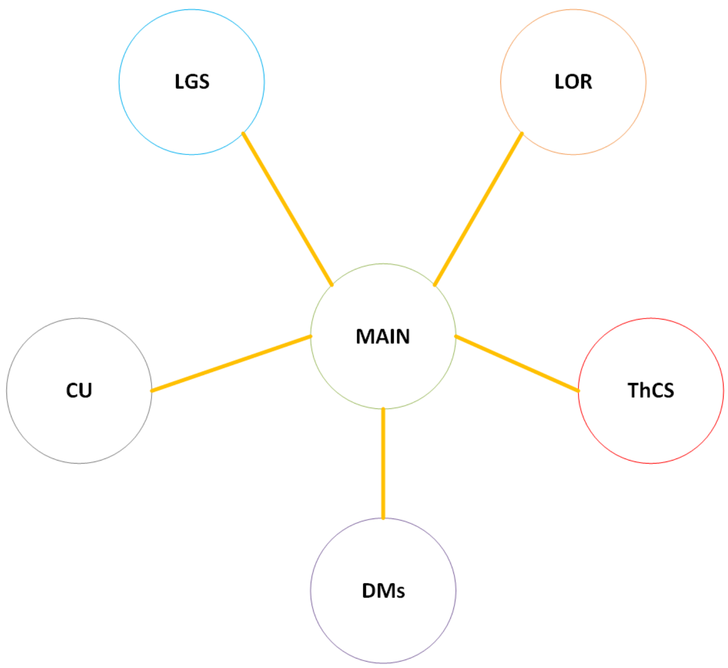

Figure 4. EtherCAT network distribution topology.

The decision of having all the MORFEO subsystems under the same EtherCAT network was made following a trade-off analysis among multiple alternative topologies. A more detailed description of this trade-off process can be found in [6].

As for the Control network, one copper cable for EtherCAT connection is provided to each subsystem. To connect themselves to the network, the subsystems employ EtherCAT couplers with ID switches. Each EtherCAT segment is manually assigned a unique ID, and can then be located at any point in the EtherCAT network. This way, wrong connections to the EtherCAT network are prevented.

For the subsystems that need to be synchronized, they can be connected to the ELT Time Reference Network either via NTP (Network Time Protocol) or PTP (Precision Time Protocol), for applications that need an accuracy of the order of few microseconds. The connection can be done either via copper or fibre; either way, PTP will be available only in the time reference network, and the devices which require it will need a dedicated network interface. Since network switches compliancy to the PTP version and profile could be an issue, the best baseline strategy to distribute the network connection for PTP usage is to bring a devoted one-to-one connection from each PTP client to the MORFEO SCP. The media could be either copper or fibre depending on the client needs. This architecture will assure not only the proper propagation of the synchronization signals but also of the diagnostic ones from clients to server to monitor devices status and to diagnose any synchronization issues.

Likewise, Deterministic Network connections are made directly from the SCP to the corresponding subsystems.

2.3 Electronic cabinets general design

The Instrument Control Hardware is located into standard COTS 19” cabinets, with external overall dimension of 600x800x2000 mm, with the two exceptions of the NGS WFS module control electronics cabinets [7], which has a height of 1800 mm, and the Proximity Electronic Cabinet, which has a custom height of 1000 mm.

The doors and panels are opaque to prevent light pollution, unlike the standard cabinet model.

As for ESO requirements, during night time the temperature difference between the MORFEO Control Electronic subsystem (or any associated equipment) outer surface and the ambient air in still wind conditions shall not be larger than ±1.5 ºC. The maximum temperature difference during day time is of ±2.5 ºC [8] [9].

An active control of the cabinet temperature will be employed to satisfy the requirement. This control will be achieved via the cabinet built-in air/water heat exchanger. The cabinets will be put in cascade and cooled using the coolant coming from the MORFEO Service Connection Point. More information on the MORFEO Thermal Control design can be found in [10].

In the current baseline, the MORFEO PLC is in charge of the cabinet temperature monitoring and of the coolant flow regulation.

To this purpose, the following devices will be installed in each cabinet:

- A voltage controlled hydraulic valve, to regulate the coolant flow inside the cabinet heat exchanger.
- A leakage sensor, to detect possible coolant leakage and intervene before the hardware is damaged.
- A flow rate sensor, to measure the coolant flow and correct it in a closed loop.
- PT100 temperature sensors, to monitor the ambient air temperature, the temperature inside the cabinet and the temperature of the coolant inlet/outlet.

Once connected to the sensors and to the valve the PLC starts controlling the cooling flow rate, using a flow rate sensor to receive feedback on the current flow rate of the coolant, in order to make the cabinet temperature track the ambient temperature.

Two PT100 sensors will be used to monitor the cabinet temperature and compare it to the ambient temperature.

As further means of keeping the outer temperature of the cabinets in the interval specified by the requirement, their walls will be thermally insulated with a layer of insulating material.

Given the design of the cabinet, with its air/water heat exchanger located on the base with a fan tray on the top, and air ducts along the sides of the cabinet, the insulating layer has to be applied to the external walls on the cabinet, and then covered with metal panels to prevent degradation of the material.

A SIL2 temperature limiter is employed to directly prevent damage due to over temperature, and issue warnings to the PLC.

Since the base of the cabinet is occupied by the heat exchanger and its sides by the cooling air path, in order to keep both doors functional, the cables exit the cabinet through the area of the top that is not occupied by the fan tray. There are two areas next to the fan tray, each of about 470 mm x 97 mm, where the connectors can be installed, as shown in Figure 5.

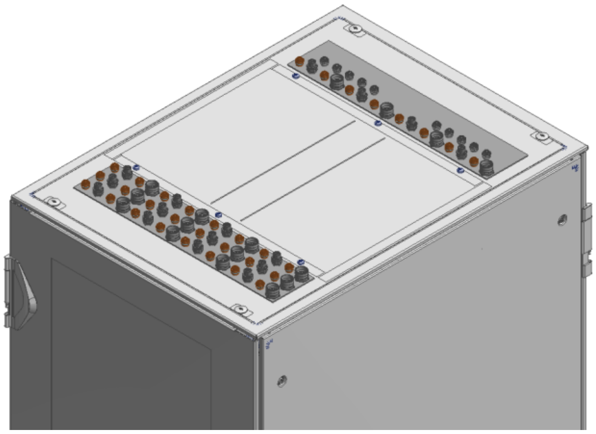

Figure 5. Conceptual CAD of the connectors layout on top of the cabinet.

Power cables will instead arrive from the bottom of the cabinet, and plugged into terminal blocks inside of it.

To attach the cabinets to the platform, while minimizing the transfer of vibrations from the fans inside of the cabinets to the platform itself, a damping system based on COTS components will be used. A custom made earthquake pedestal will be employed so that the cabinets can withstand Bellcore Zone 4 earthquakes.

The overall height of the custom cabinet should increase by less than 100 mm.

3. MAIN SYSTEM CABINETS DESIGN

The Main System control electronics will be located inside four cabinets:

- Power Distribution Cabinet (PDC)
- Post Focal Relay Optics Cabinet (PFROC)
- Accessory Cabinet (AC)
- Proximity Electronics Cabinet (PEC)

The control electronics will be mainly directly mounted on DIN rails, without the need of racks. This way, air circulation inside the cabinet is facilitated, and no additional fans have to be added. However, there are two exceptions, consisting of the Deformable Mirrors and LGS control electronics, which are hosted inside sub-racks. This solution allows for the independent integration and testing of the two subsystems.

As far as possible, the general layout of each MORFEO electronic cabinet is harmonized. Enough space for cables and connectors is left at the top of the cabinet.

3.1 Power Distribution Cabinet

The Power Distribution Cabinet, located on the intermediate platform, has the main function of distributing single-phase power to the other Main System cabinets and to all the other subsystems. The following devices are mounted inside:

- A single PLC that controls all functions of MORFEO
- Cabinet management I/O terminals
- Ethernet switch for Control network delivery to all the subsystems
- EtherCAT junction for distribution of the EtherCAT network to all the cabinets
- Touch panel that provides a visual interface to all the subsystems
- Power supplies
- Power distribution and protection devices

The internal layout of the PDC is shown in Figure 6.

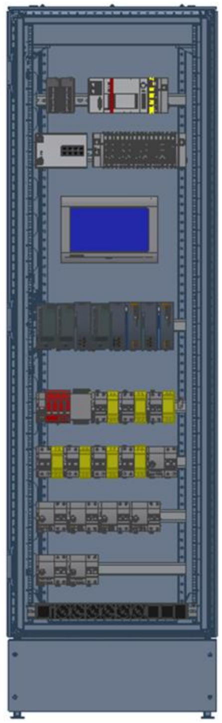

Figure 6. Power Distribution Cabinet layout.

The MORFEO PLC is expected to always be switched on. The first power-up of the system is managed by the Main System. First, the Main System PLC is switched on manually, via the Power Distribution Cabinet mains switch. In this cabinet, a PLC module monitors the three-phase power. Then, if no anomalies are detected, the PLC itself takes care of the gradual startup of its loads, including the other subsystems (provided that the respective cabinets manual switches are switched on), by remotely controlling power relays and following an established routine.

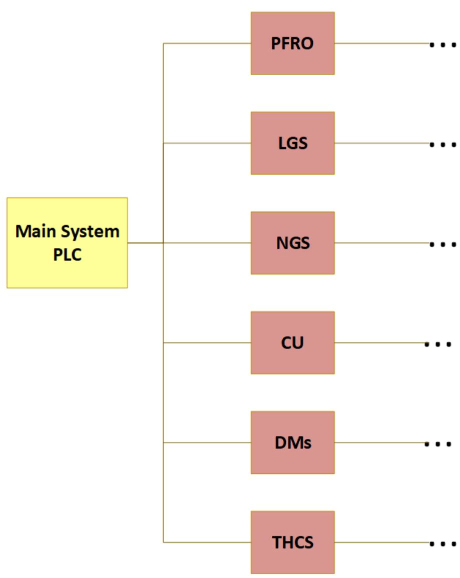

Figure 7. ICH power-up scheme.

Each subsystem could follow the same concept, using the required terminals and devices, for the startup of their loads. The same process is followed if an event occurs, bringing to the shutdown of the system.

The PLC itself will be remotely controlled, to allow for completely switch on and off the entire system without any manual intervention on either platform. This will be useful for maintenance and cycling purposes.

3.2 Post Focal Relay Optics Cabinet

The Post Focal Relay Optics Cabinet, located on the Nasmyth platform, contains control electronics for the PFRO motorized functions. The devices mounted in this cabinet are:

- Optomechanics motor drivers
- Cabinet management I/O terminals
- Power supplies for PLC terminals
- Motor power supplies
- PLC terminals for PT100 sensors
- Protection devices

The cabinet layout is shown in Figure 8.

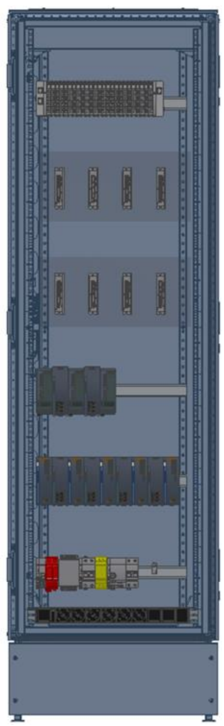

Figure 8. Post Focal Relay Optics Cabinet layout.

The motor drives will control seven different axes. Three each are employed for controlling the tip/tilt movements of two optomechanical elements, with three degrees of freedom [11]. The seventh motorized function is a rotary stage that allows to redirect the light either towards MICADO or the second instrument.

Each motorized function consists of a brushless DC motor, an absolute encoder, and two limit switches.

Since a BLDC motor does not have mechanical brushes that wear down with time, it requires a lower level of maintenance. Plus, no dust is generated by the action of the brushes.

The absolute encoder presents an EnDat 2.2 interface. This type of interface allows for longer cables compared to other standards like SSI.

Finally, proximity type limit switches are used instead of mechanical ones, since the absence of physical contact provides longer life and better repeatability. The limit switch type is chosen so that the circuit is broken when the switch is activated.

Two PT100 sensors are used to monitor the temperature of each optomechanical element, to measure the temperature of the optics surface and of its mechanical support.

3.3 Proximity Electronics Cabinet

The Proximity Electronics Cabinet is a customized half cabinet containing electronics with critical cable lengths. For this reason, this cabinet is located on the Nasmyth Platform, near the MORFEO Main Support Structure and the LGS wavefront sensor module, as shown in Figure 9.

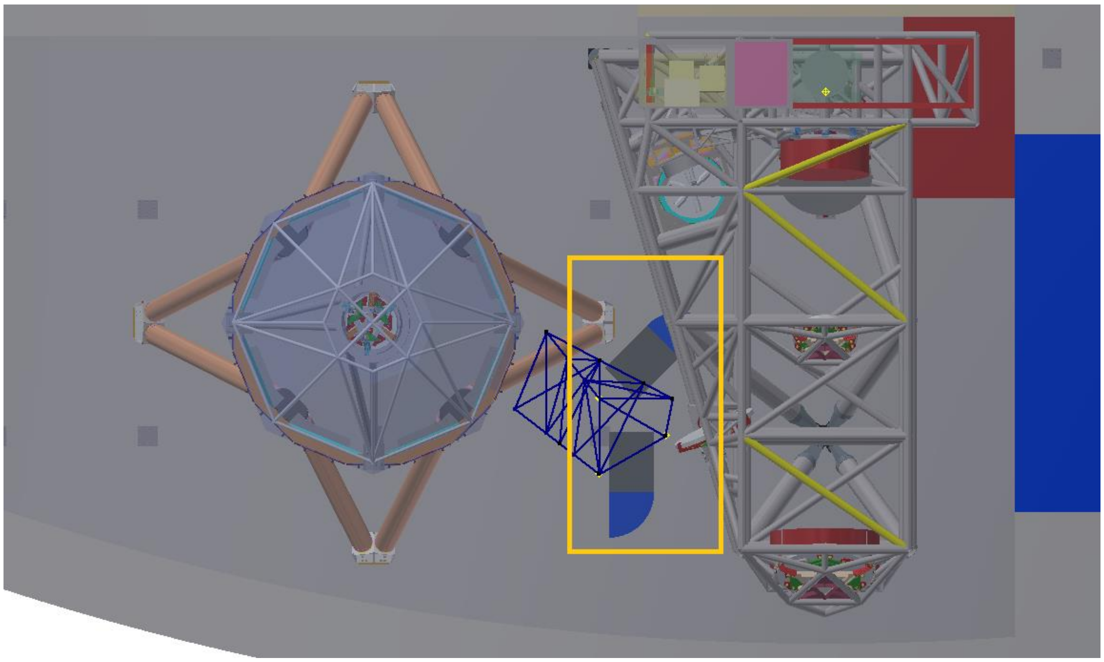

Figure 9. Position of PFROC and PEC on the Nasmyth platform.

In the Figure, the two cabinets on the Nasmyth are enclosed in yellow, the blue volume showing the space needed to open the cabinet door. Given the limited available space, the internal layout of the cabinets is designed so that only access to the front door is needed.

The following devices are mounted in the Proximity Electronics Cabinet:

- LGSWFS module subrack (piezo controllers and cameras power supplies)
- Cabinet management I/O terminals
- Power supplies
- Protection devices

The internal layout of the cabinet is shown in Figure 10.

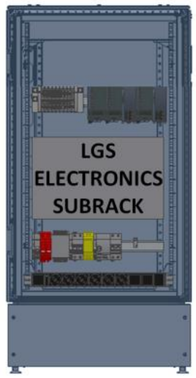

Figure 10. Proximity Electronics Cabinet layout.

3.4 Accessory Cabinet

The Accessory Cabinet is located on the intermediate platform, and contains control electronics and power supplies for DMs and CU selector motors [12]. The following devices are mounted in this cabinet:

- Motor drivers for CU selector
- Deformable Mirrors electronics subrack
- Cabinet management I/O terminals
- Power supplies
- Protection devices

Figure 11 shows the layout of this cabinet.

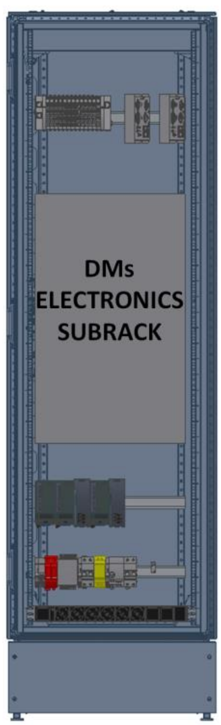

Figure 11. Accessory Cabinet layout.

The two motor drivers control the movement of the Calibration Unit selector, a horizontal slider with three different positions, allowing deployment of either the MICADO Calibration Assembly or the MORFEO Calibration Unit, while in its third position it clears the path for the light coming from the telescope. A more detailed description of the electromechanical design of the selector can be found in [13].

4. HARNESS DESIGN

Harness is designed to be reliable and maintenance friendly. Cables are put inside metallic conduits to protect them from abrasions and external agents.

All established procedures in terms of shielding, grounding and routing are taken in order to comply with all EMC requirements and preserve the integrity of the signals. The routing path takes into account the maximum bend radius of the cables, and at least 40% of the space inside the conduits is kept available for possible future installations.

The cables coming from the cabinets placed on the intermediate platform are routed up using ducts that reach the Nasmyth platform at its main support points.

On the Nasmyth platform, the cables are routed to the MORFEO Main Support Structure [14][15] via one entry point through the structure thermal enclosure, together with the cables routed from the top of the two cabinets hosted on the Nasmyth itself. The cables to be routed from the MORFEO SCP and the Power Distribution Cabinet to the NGSWFS module cabinets reach the Nasmyth platform in proximity to the MICADO derotator cable wrap entry point.

Inside the Main Support Structure, a 200 mm x 80 mm cable tray branches to all active devices inside the structure, as shown in Figure 12.

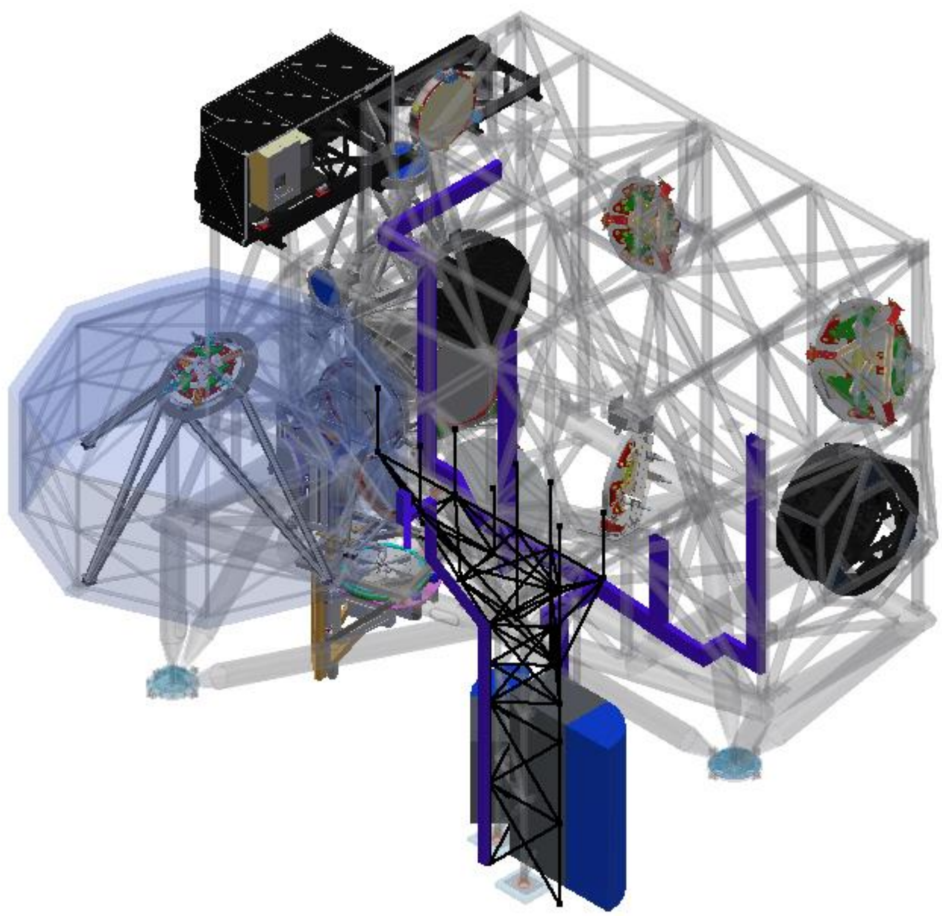

Figure 12. Harness concept (in violet) inside MORFEO Main Support Structure.

To route the motor controllers and PT100 terminals, hosted inside the PFROC, to the optomechanical element placed over MICADO, a 100 mm x 80 mm cable tray is supported by the MORFEO-MICADO thermal duct support structure itself.

Finally, the cables for the Calibration Unit selector are routed in a cable chain, so that the cables can move with the slider.

The system will be connected to a single grounding point, in a star-like topology. This scheme will also prevent the creation of ground loops. More specifically, every part of a subsystem (including on-field devices and cable trays) is connected to a ground rail in the corresponding cabinet. In turn, the ground bars of all the cabinets are connected to the ground rail in the Power Distribution Cabinet. Finally, the PDC ground is connected to the telescope ground through the MORFEO SCP.

Considerations on the RAMS aspects of the Instrument Control Hardware Main System can be found in [16] and [17].

5. CONCLUSIONS

The MORFEO Instrument Control Hardware design was submitted to the Preliminary Design Review in the first half of 2021. No critical issues were identified during the review process.

This paper describes the preliminary design of the Instrument Control Hardware that was updated in the months following the PDR, as the MORFEO project approaches Phase C. The Final Design Review is expected to take place in 2023.

6. ACKNOWLEDGMENTS

The MORFEO instrument is developed in the framework of the Agreement No. 65221/ESO/15/67001/JSC between the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) and the Istituto Nazionale di Astrofisica (INAF) on behalf of the Consortium consisting of INAF, Institut National des Sciences de I'Univers du Centre National de la Recherche Scientifique (INSU/CNRS) acting on behalf of the Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) and of School of Physics at the National University of Ireland Galway (NUIG).

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