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# MAORY Instrument Control Hardware: general overview

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## ABSTRACT

This paper provides a description of the Instrument Control Hardware design for MAORY (Multi-conjugate Adaptive Optics RelaY), a first light instrument for ESO ELT. The MAORY Instrument Control Hardware is in charge of the control electronics of the entire system. It comprises all the implemented electronic devices (power supplies, PLC CPUs and terminals, motor drivers, control panel, network switches, sensors) and the harness used to connect them. The instrument control system architecture is based on the use of PLC and EtherCAT fieldbus protocol, which allows for a distribution of PLC terminals controlled by the same CPU that do not have to be physically located in the same place to communicate among each other.

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

## 1. INTRODUCTION

MAORY is a post-focal adaptive optics module for the Extremely Large Telescope, ELT, designed to help compensate for distortions of the light caused by turbulence in the Earth's atmosphere [1][2]. MAORY will support the MICADO near-infrared camera in order to have stable and sharp images across a large field of view in the near infrared [3]. MAORY will also support a second instrument. The adaptive optics module will be placed on the Nasmyth Platform A of the telescope [4].

The MAORY Electronics consist of the following subsystems:

- Electronics for Main System (in charge of Power Distribution, Post Focal Relay Optics and Accessory cabinets)
- Electronics for Calibration Unit
- Electronics for the Deformable Mirrors (located in the Main System cabinets and on MAORY main structure)
- Electronics for Thermal Control
- Electronics for the Natural Guide Star (NGS) wavefront sensor module
- Electronics for the Laser Guide Star (LGS) wavefront sensor module

This division into subsystems allows the independent design and testing of MAORY functions, helping parallel development, and simplifying the interfaces, which are based on the essential services.

In this paper the general Control Hardware architecture and Main System Instrument Control Hardware will be described.

## 2. MAORY INSTRUMENT CONTROL HARDWARE OVERVIEW

The MAORY Instrument Control Hardware (ICH) is in charge of the control electronics of the system and the harness that connects them. The Instrument Control Hardware includes the entire electronics infrastructure required to control the Instrument.

The MAORY electronic architecture design follows these guidelines:

- It is based on a distributed system composed by industrial standard Commercial-Off-The-Shelf (COTS) components.
- The communication between the components is based on industrial, standard, real-time buses.

The architecture of the control system is based on the paradigm of decentralized functions and the extensive use of field buses, drawing on industry standards. Each subsystem has dedicated PLC CPU and terminals, in order to facilitate independent integration and verification for every subsystem. The use of industry standards and COTS elements allows for rapid development, lower costs for spare parts and a widespread understanding of architecture among specialized firms. In the case of MAORY, the choice of active components (mainly of Beckhoff firm) is summarized in Table 1.

Table 1. Active components employed in MAORY Instrument Control Hardware.

<b>Topology</b>	<b>Model</b>
PLC	CX2030
PLC CPU Power Supply	CX2100-0004
Digital Input	ES1808
Digital Output	ES2808
Current Analog Input	ES3002
Voltage Analog Input	ES3052
Analog Input terminal Pt100	ES3202
Voltage Analog Output	ES4104
External Synchronization Interface	EL6688
3-phase Power Measurement	ES3403
DC Motor Drive	ELMO Gold Whistle – G-DCWH15/100EE
EtherCAT Coupler	EK1100
EtherCAT Extension	EK1110
Safety Logic Terminal	EL6910
Safety Digital Input	EL1904/EL1918
Safety Digital Output	EL2904/EL2912

Figure 1 offers an overview of ICH and the various subsystems cabinets.

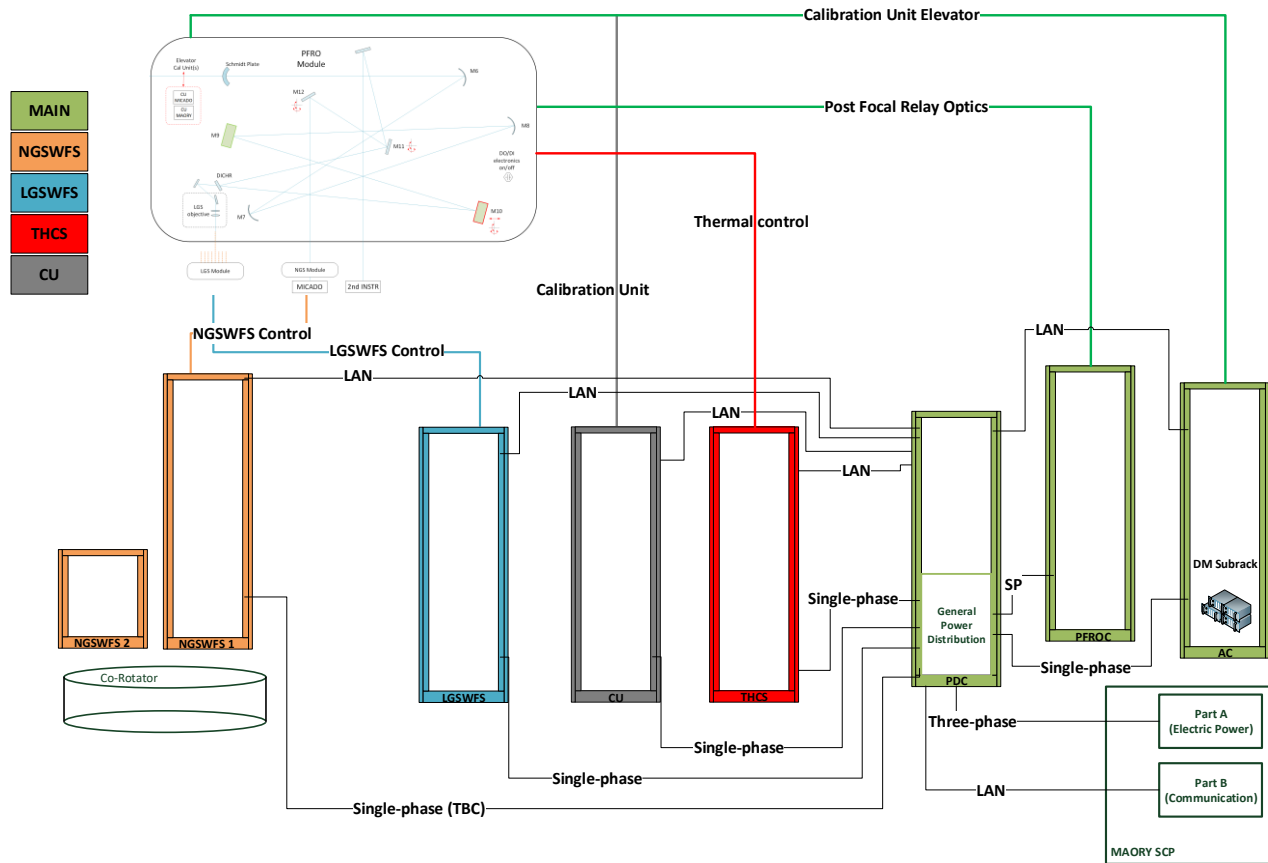


Figure 1. MAORY Instrument Control Hardware overview; the three Main System cabinets are shown in green.

## 2.1 Main System cabinets general design

Instrument control electronics are housed into standard 19" cabinets, with external overall dimensions of 600 mm x 800 mm x 2000 mm. The doors and panels are opaque to prevent light pollution. Each cabinet is equipped with its own built-in air/water heat exchanger, to manage the cabinet temperature and keep it compliant with thermal requirements. The PLC actively controls the coolant flux. More specifically, the PLC receives feedback on the current flow rate of the coolant, acting on a hydraulic valve in order to make the cabinet track the ambient temperature. Two PT100 sensors are employed to monitor the cabinet temperature and compare it to the ambient temperature. The sensors also detect over temperature and give a warning to the PLC, that can act accordingly on the devices inside the cabinets. As further means of keeping the outer temperature of the cabinets in the interval specified by the requirement, their walls are covered with a layer of thermally insulating material. More information on the MAORY thermal control system is found in [5].

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, most of the cables will exit the cabinet through the area of the top that is not occupied by the fan tray. In Figure 2 a technical drawing of the cabinet, and in particular its top cover, is shown. There are two areas next to the fan tray, each of about 470 mm x 96 mm, where the connectors can be installed.

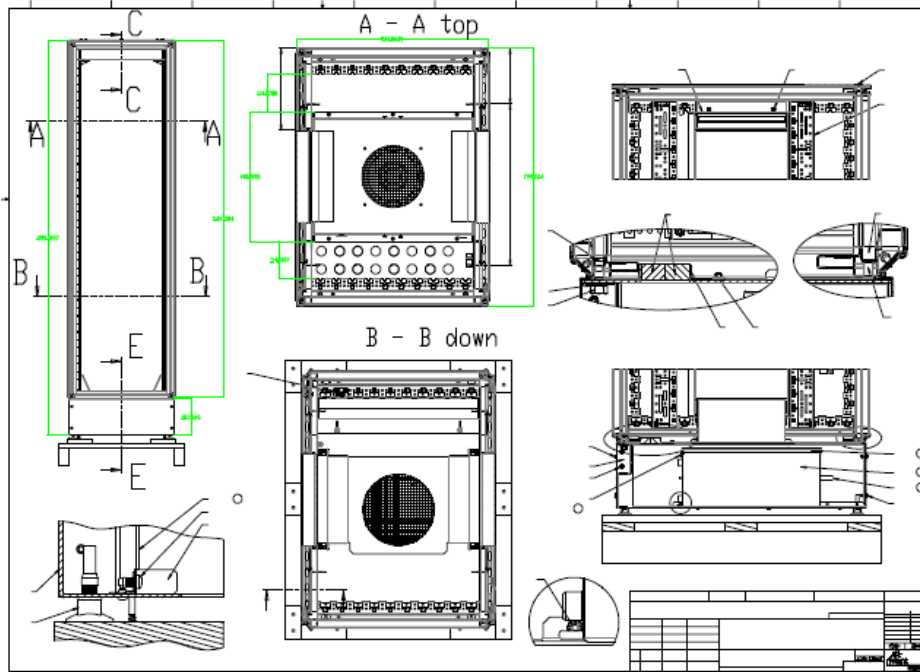


Figure 2. Cabinet technical drawing.

Figure 3 shows a CAD model of the cabinet with the connectors installed on its top. Power cables will instead arrive from the bottom of the cabinet, and plugged into terminals inside of it. For cabinets positioned far from the MAORY main structure, routing of all cables from the bottom might be preferred.

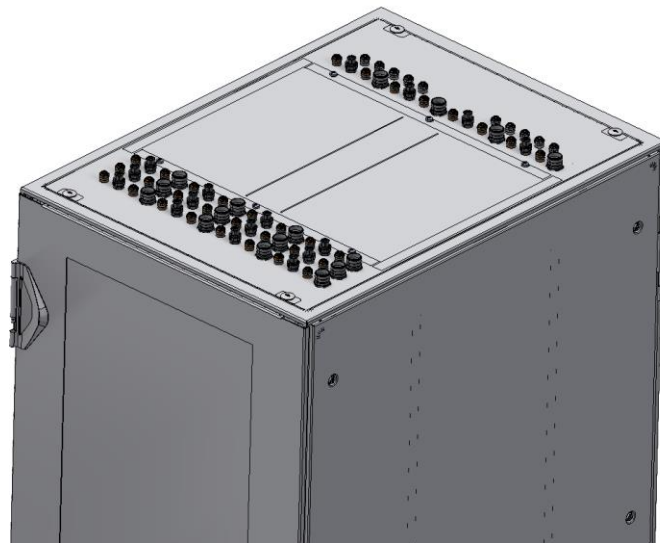


Figure 3. Position of the connectors on the top of the cabinet.

The modules used for I/O and other tasks required by the ICH can be classified under the following types:

- Digital I/O, for devices with discrete control signal and status output
- Analog I/O, for devices with continuous control signal and status output

- Motion control modules, for the motorized functions
- Safety

## 2.2 Main system cabinets layout

The instrument control hardware electrical and electronics devices and functions of Main System are distributed among the following cabinets:

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

The instrument control hardware requires services from ELT Service Connection Point (SCP) and receives commands from instrument control software.

## 2.3 Power Distribution Cabinet

The Power Distribution Cabinet main function is the distribution of single-phase power to the other Main System cabinets and to all the other subsystems. The three-phase power is provided only to the PDC directly from the SCP. 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.

The distribution inside the cabinet is shown in Figure 4.

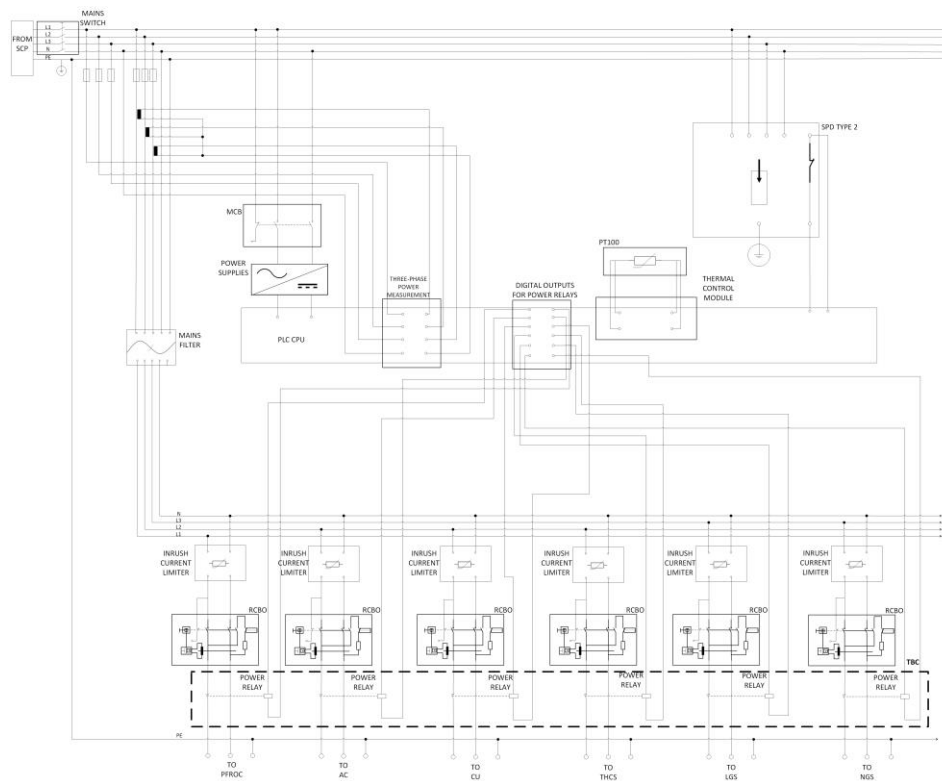


Figure 4. Three-phase power distribution scheme.

The three-phase power is monitored by a PLC module, 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
- A residual current device with overcurrent protection
- A contactor that can switch on and off the power supplied to the corresponding subsystem

LAN is provided from the SCP to the PDC, where an Ethernet switch is located, and from there, off to the PLC of each subsystem. A Control network connection scheme is shown in Figure 5.

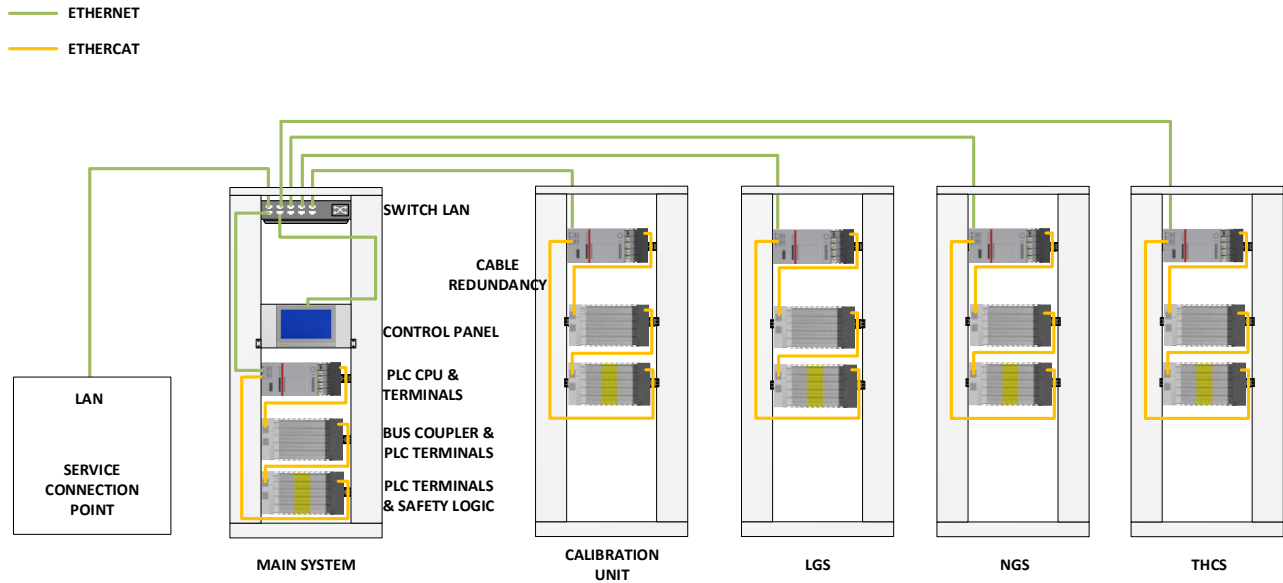


Figure 5. Control network connection scheme.

EtherCAT connection branches downstream of the single PLC to its slave devices (PLC terminals through E-bus, EtherCAT couplers, other EtherCAT compatible devices). Cable redundancy is employed, with the last device of the EtherCAT series being connected to the PLC, to form a loop in a ring-like topology. This way, in case of malfunction of a single cable or terminal, the downstream devices are not cut off, communicating through the redundant path.

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. Since network switches compliance 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 MAORY SCP. 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.

The PLCs of different subsystems can communicate with each other through the EtherCAT Automation Protocol (EAP). Safety logic of different subsystems can also use EAP to communicate.

The Main System also hosts a Beckhoff control panel, managed through TwinCAT HMI, that can communicate with all the subsystem PLCs via ADS protocol in its multi-runtime mode.

The following devices are mounted inside the PDC (Figure 6):

- A single PLC that controls all functions of the Main System
- I/O terminals and safety modules for cabinet management
- A control panel that provides a visual interface to all the subsystems

- An Ethernet switch for control network delivery to all the subsystems
- Power supplies
- Power distribution and protection devices

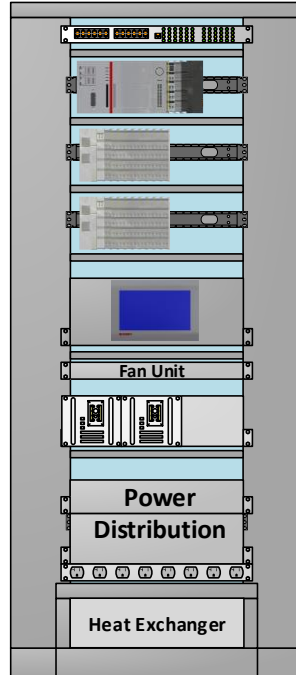


Figure 6. Power Distribution cabinet layout.

## 2.4 Post Focal Relay Optics Cabinet

The PFRO mainly contains control electronics for the Post Focal Relay Optics motion functions [6]. The following active functions for the optomechanics are employed:

- Tip/Tilt movement for M11 (using three degrees of freedom)
- Tip/Tilt movement for M12 (also with three degrees of freedom)
- Rotary stage to select MICADO or a second instrument (achieved by moving M11)

Each motorized function is composed of a DC brushless motor with Hall sensors, a linear absolute encoder, and upper/lower limit switches. Furthermore, two PT100 sensors are employed to monitor the temperature of each optomechanical element.

Thus, the PFRO cabinet contains the following devices (Figure 7):

- Motor drivers
- PLC terminal modules for PT100 sensors
- I/O terminals and safety modules for cabinet management
- General power supplies
- Motor power supplies
- Protection devices

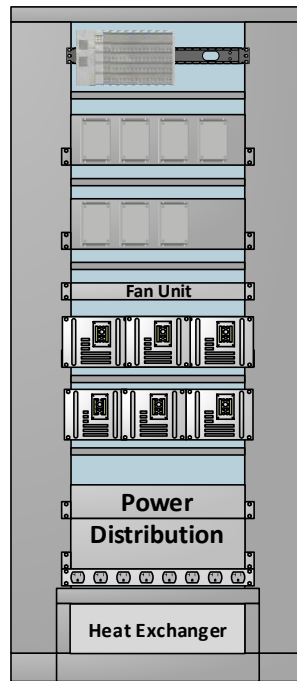


Figure 7. Post Focal Relay Optics cabinet layout.

## 2.5 Accessory Cabinet

Finally, the Accessory Cabinet contains electronics for the motorized function that is responsible for moving the elevator in which the MAORY and MICADO Calibration Units are installed [7]. The cabinet also hosts a subrack containing dedicated electronics for the two Deformable Mirrors (DMs) employed in MAORY.

More specifically, the following devices are mounted in this cabinet (Figure 8):

- Motor driver for Calibration Unit elevator
- Deformable Mirrors Real Time Kinematics Controller and Positioner Supervisor
- Deformable Mirrors power supplies and batteries
- I/O and safety terminals for cabinet management
- General power supplies
- Motor power supplies
- Protection devices

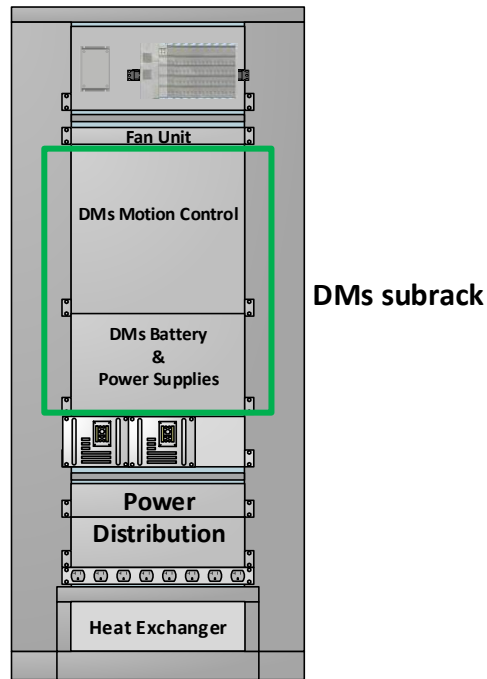


Figure 8. Accessory cabinet layout.

### 3. HARNESS DESIGN

All harness is designed in order to achieve maximum reliability. The cables are placed on metallic conduits, with a separate section dedicated to the coolant pipes.

The harness paths are chosen in order to minimize cable length, while complying with all constraints, such as:

- Bend radius of each cable that is never smaller than the minimal value as specified by the cable manufacturer.
- Protection against damage from abrasion, contact with sharp edges or protrusions and environments.
- Cables positioned as close as possible to structural components, according to the EMC requirements.
- Earthed conductors routed parallel to live conductors to keep earth loop areas as small as possible.

The cable tray for power and network distribution among the cabinets will be installed under the Nasmyth platform grid. The harness layout has been updated, compared to the one designed for the previous MAORY main support structure [8][9]. The harness connecting the control terminals located inside the cabinets to the devices inside the MAORY main structure has a single entrance point through the main structure cover, with the cable trays branching inside the structure itself, as shown in Figure 9. A more in-depth description of the MAORY main support structure can be found in [10][11].

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.

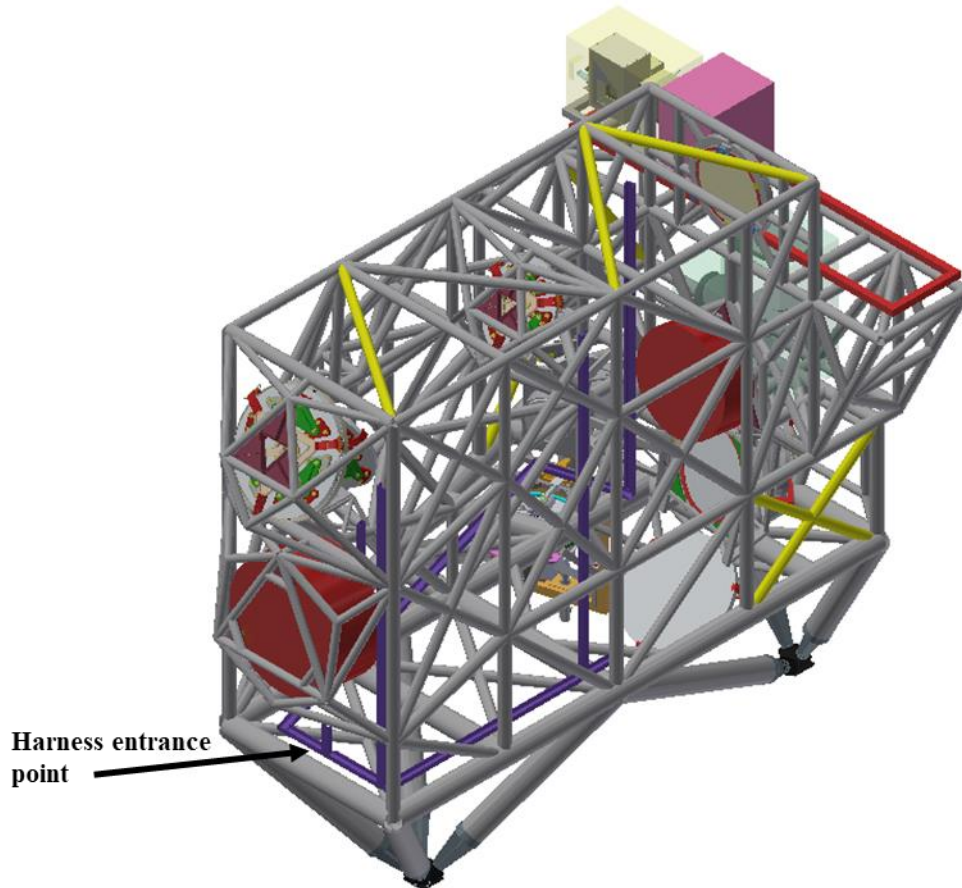


Figure 9. Harness path (in violet) inside MAORY main structure.

#### 4. DISTRIBUTED ARCHITECTURE APPROACH

Another solution for the ICH design currently under investigation further exploits the EtherCAT fieldbus protocol for remote communication with the PLC, with the PLC modules and motor drivers that control all the electronics on the MAORY main structure being located in proximity of the main structure itself in a distributed connection approach.

The PLC I/O terminals and motor drivers will be put inside insulated enclosures, one for each mirror. The single enclosure represents the “brick” of the distributed architecture, and can be identically replicated as many times as it is necessary for the design.

The devices to be moved near the MAORY main structure are the following:

- Analog Input terminals for the PT100 probes that monitor the mirrors temperature.
- Motor Drivers to control the motorized functions of the optomechanics.
- I/O terminals to manage all auxiliary and feedback functions required on the bench.
- Safety terminals to manage possible interlocks in order to avoid potential risks.

Each box is easily connected to the system via connectors installed on its external faces, as shown in Figure 10, and constitutes an LRU in case of malfunctions.

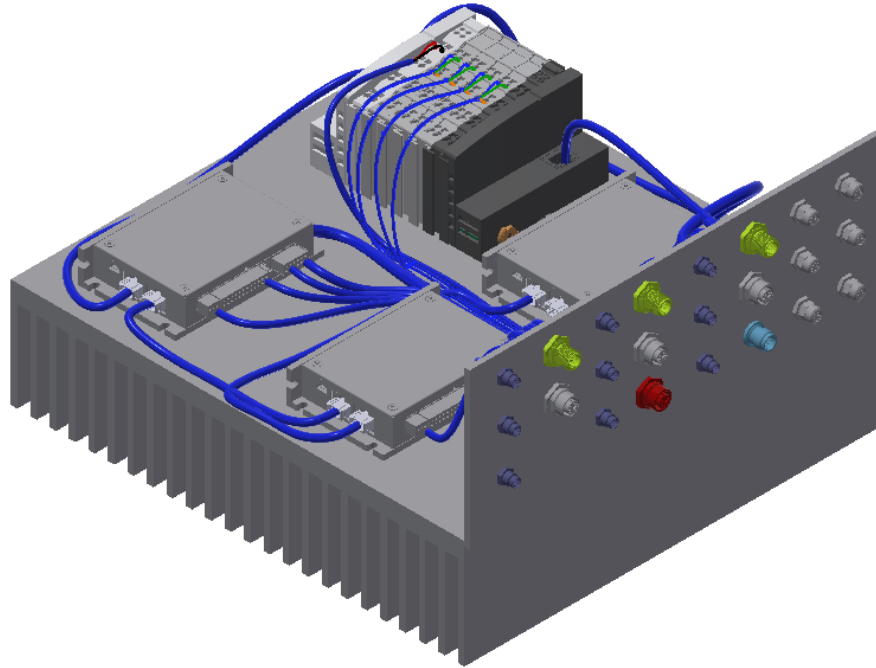


Figure 10. Distributed architecture “brick”.

The EtherCAT and power line arrive to the first brick from the PFRO cabinet through the cable tray. They also exit as output from the same box in order to be carried downstream to the next bricks. Every other type of connection (motor cables, encoders, limit switches, PT100) goes directly from each brick to its corresponding system, and does not need to be carried to the main structure from the cabinets placed on the Nasmyth platform.

In the distributed solution, it is imperative that the devices placed outside of the cabinets fulfill the restrictive requirements about heat dissipation in air. Great part of the trade-off study between centralized and distributed architectures is concerned with the study and test of the actual power dissipation of the devices and the passive or active means to be employed in order to comply with the requirements.

A more in-depth description of the activities carried out for this study is found in the paper “Design and analysis of an innovative distributed architecture for ESO instrument control hardware”, presented in this Conference [12].

## 5. SUBSYSTEMS INTEGRATION AND DESIGN PROCEDURE

The process of designing a system such as control electronics cannot be detached from the needs of the various subsystems. For this reason, the ability to define the architecture is temporally linked to the availability of the necessary information. To minimize this time dependence and proceed in an 'almost parallel' way, it is important to carry out a careful study of the design choices, and the corresponding dependencies. Interactions at system and subsystem level are crucial to gradually eliminate uncertainties, and to take decisions based on more defined and certain options.

A time graph summarizing this approach is shown below in Figure 11.

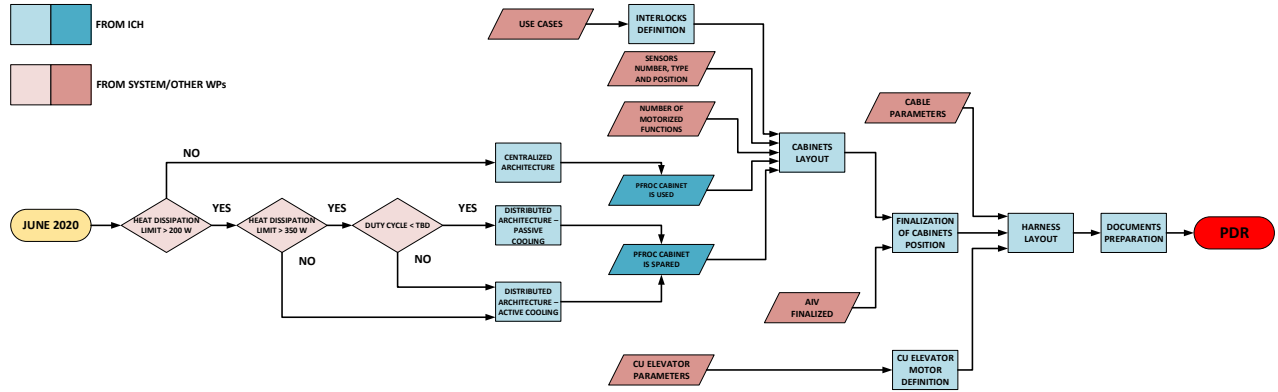


Figure 11. Time graph of a design process branch.

## 6. CONCLUSIONS

MAORY Instrument Control hardware current design was presented in this paper. In particular, the architecture of the Main System, responsible for power and network distribution, harness, and control of the Post Focal Relay Optics and Calibration Unit motorized functions, was described.

MAORY is now approaching the Preliminary Design Review, in order to conclude Phase B of the project.

## 7. ACKNOWLEDGMENTS

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