

System Engineering at the MEGARA project

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ABSTRACT

MEGARA (Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía) is a facility instrument of the 10.4m GTC (La Palma, Spain) working at optical wavelengths that provides both Integral-Field Unit (IFU) and Multi- Object Spectrograph (MOS) capabilities at resolutions in the range $R=6,000$ -20,000. The MEGARA focal plane subsystems are located at one of the GTC focal stations, while the MEGARA refractive VPH based spectrograph is located at one of the Nasmyth platforms. The fiber bundles conduct the light from the focal plane subsystems to the pseudo-slits at the entrance of the spectrograph.

The project is an initiative led by Universidad Complutense de Madrid (Spain) in collaboration with INAOE (Mexico), IAA-CSIC (Spain) and Universidad Politécnica de Madrid (Spain) and is developed under contract with GRANTECAN. The project is carried out by a multidisciplinary and geographically distributed team, which includes the in-kind contributions of the project partners and personnel from several private companies.

The MEGARA system-engineering plan has been tailored to the project and is being applied to ensure the technical control of the project in order to finally meet the science high-level requirements and GTC constraints.

Keywords: MEGARA, GTC, System engineering, requirements and specification, technical budgets, RAMS, Product Tree, Interfaces, verification, configuration control, non-conformities, anomalies.

1. INTRODUCTION

Systems engineering provides the methodology for developing a system in a structured and orderly manner. This methodology involves following several steps, which include specifying the system requirements, mapping them to the initial needs, and, finally, preparing and carrying out the system verification. The objective of this process is to produce a system that fulfills the initial needs, which is essential for reaching the project success.

A project success occurs when the system meets its objectives and the project is carried out within the cost and schedule assigned to it. In order to accomplish it, the project must be carried out with a good organization. The Systems Engineering Plan provides the means to organize the technical effort of the project.

System Engineering is defined as the interdisciplinary approach governing the total technical effort to transform the initial requirements into the system solution. A System Engineering Plan must describe the approach, techniques, tools, organization, planning and technical effort needed to achieve the project objectives. Systems Engineering considers the whole system life cycle. It means, it is considering from the earliest stages of the project not only to design phase of the system but also the production, integration and operation phases. In this way, the production, maintenance, operation and logistics requirement are taken into account from the beginning.

The System Engineering Plan must be tailored for that particular project. This Plan must include the activities to be performed in each phase of the project, the milestones to be met, the documentation to be generated and a schedule of technical reviews to assess the progress achieved in each project milestone.

Therefore, Systems Engineering helps to ensure that the system is correctly developed from the beginning, minimizing risks and anticipating problems that may arise.

The main tasks that should be carried out by the System Engineer are summarized as follows:

- Implement the requirements engineering, which aims to ensure that the high-level requirements are correctly interpreting user needs and including all environmental and external interface constraints and ensure traceability with the lower level specifications.
- Perform system analysis, resolve requirement conflicts, carry out trade-off, develop and use simulation models, analyze project risks and perform RAMS analysis.
- Define and maintain system configuration (define Product Tree and Interface Table) and manage non-conformities and configuration changes that could arise during the system development.
- Prepare and execute the Integration and Verification Plan.
- Prepare the Operation and Maintenance Plan.

During the Conceptual Phase of the MEGARA project, the MEGARA System Engineering Plan was defined considering all project phases, from conceptual design to the final instrument acceptance at GTC. The activities are reviewed at the end of each phase in order to add the needed details to the tasks to be performed in the following phase. Currently, MEGARA has already delivered the CDR documentation and is ready to enter into manufacturing. This article summarizes how system engineering has been implemented at MEGARA and the current status of the activities.

2. MEGARA OVERVIEW

MEGARA (Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía) is an optical Integral-Field Unit (IFU) and Multi-Object Spectrograph (MOS) designed for the GTC 10.4m telescope in La Palma.

MEGARA offers two IFU-type modes with two different bundles, one covering 12.5 arcsec x 11.3 arcsec with a spaxel size of 0.62 arcsec (Large Compact Bundle; LCB, which makes use of 100mm-core optical fibers) and another one covering 8.5 arcsec x 6.7 arcsec with a spaxel size of 0.42 arcsec (Small Compact Bundle; SCB, with 70mm-core fibers). The MEGARA MOS mode will allow observing up to 100 objects in a region of 3.5 arcmin x 3.5 arcmin around the two IFU bundles. Each of the MEGARA MOS positioners can place a mini-bundle of 7 fibers (0.62"/fiber) covering an area of 1.6" on the sky. Eight of these bundles will be devoted to the determination of the sky during the observation with the LCB IFU, so only 92 of these positioners will be available for MOS observations.

Parameter		LCB	SCB	MOS
Spaxel size		0.62 arcsec	0.42 arcsec	0.62 arcsec
Field of View		12.5 x 11.3 arcsec ²	8.5 x 6.7 arcsec ²	3.5 x 3.5 arcmin ²
$\Delta\lambda$ (EED ₈₀)	Requirement	4 pix	3.48 pix	4 pix
$\Delta\lambda$ (FWHM)	Requirement	3.6 pix	3.14 pix	3.6 pix
(R _{FWHM} = $\lambda/\Delta\lambda$) (Requirement)	LR VPHs	6,000	7,000	6,000
	MR VPHs	12,000	13,500	12,000
	HR VPHs	18,700	21,500	18,700

Table 1. Main characteristics of the MEGARA LCB and SCB IFU and MOS modes.

In MEGARA Spectrograph the optical elements are placed on an optical table. The fiber bundle(s) reach the spectrograph on the pseudo-slit, where the fibers are aligned. There are 3 pseudo slits, which can be selected to the observing position with a dedicated mechanism. The focusing mechanism is also implemented moving the pseudo slits in the optical path axis direction. Just after the pseudo slit, follows the collimator barrel that includes the rotating custom-made shutter. Then, follows the pupil position, where the VPHs shall be located (a mechanism is used to select among the 11 VPHs set on the wheel). Finally, follows the camera and the cryostat, where is hosted the CCD.

The set of VPHs that MEGARA will provide is included in Table 2.

VPH Name	Setup	R _{FWHM}	$\lambda_1\text{--}\lambda_2$ (Å)	λ_c (Å)	$\Delta\lambda$ (@ λ_c) (Å)	Δv (km/s)	lin res (Å/pix)
VPH405-LR	LR-U	6028	3653 – 4386	4051	0.672	50	0.17
VPH480-LR	LR-B	6059	4332 – 5196	4800	0.792	49	0.20
VPH570-LR	LR-V	6080	5143 – 6164	5695	0.937	49	0.23
VPH675-LR	LR-R	6099	6094 – 7300	6747	1.106	49	0.28
VPH799-LR	LR-I	6110	7220 – 8646	7991	1.308	49	0.33
VPH890-LR	LR-Z	6117	8043 – 9630	8900	1.455	49	0.36
VPH410-MR	MR-U	12602	3917 – 4277	4104	0.326	24	0.08
VPH443-MR	MR-UB	12370	4225 – 4621	4431	0.358	24	0.09
VPH481-MR	MR-B	12178	4586 – 5024	4814	0.395	25	0.10
VPH521-MR	MR-G	12035	4963 – 5443	5213	0.433	25	0.11
VPH567-MR	MR-V	11916	5393 – 5919	5667	0.476	25	0.11
VPH617-MR	MR-VR	11825	5869 – 6447	6170	0.522	25	0.13
VPH656-MR	MR-R	11768	6241 – 6859	6563	0.558	25	0.14
VPH712-MR	MR-RI	11707	6764 – 7437	7115	0.608	26	0.15
VPH777-MR	MR-I	11654	7382 – 8120	7767	0.666	26	0.17
VPH926-MR	MR-Z	11638	8800 – 9686	9262	0.796	26	0.20
VPH665-HR	HR-R	18700	6445 – 6837	6646	0.355	16	0.09
VPH863-HR	HR-I	18701	8372 – 8882	8634	0.462	16	0.12

Table 2. MEGARA VPHs.

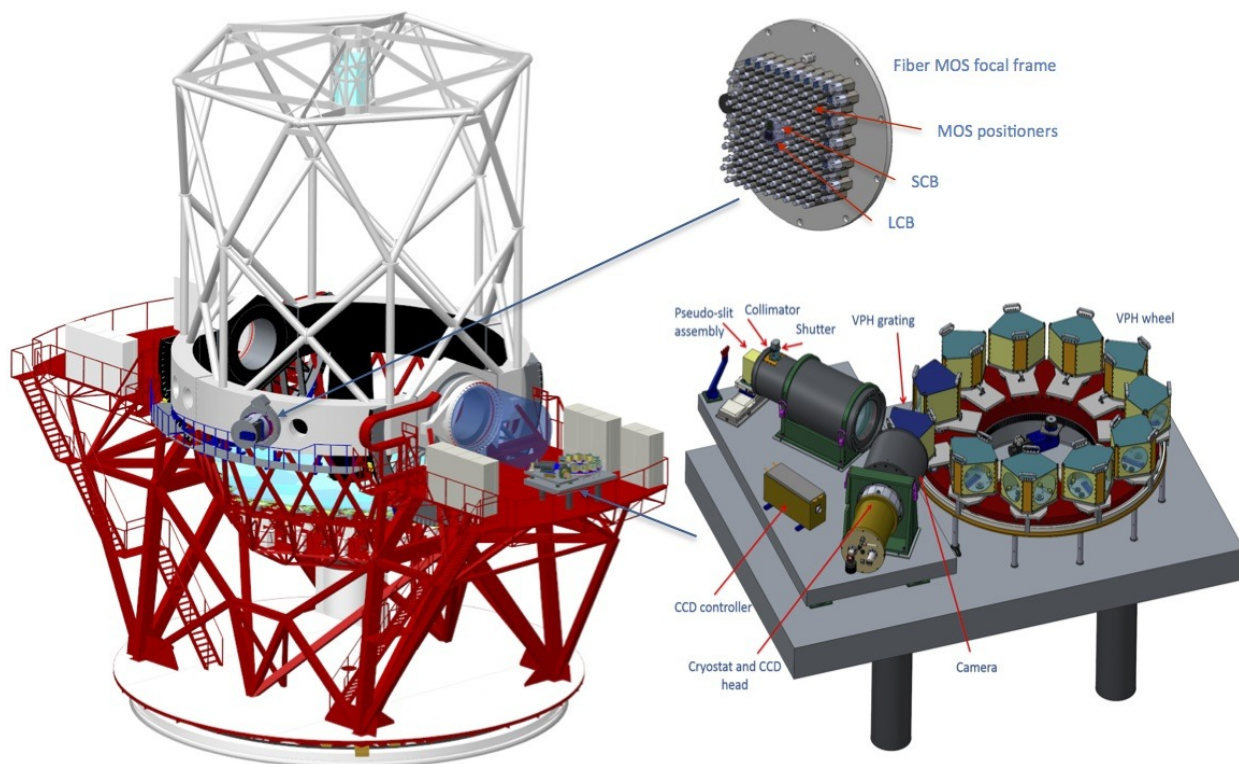


Fig. 1. Left: MEGARA at GTC. Right up: MEGARA Folded Cassegrain subsystem. Right down: MEGARA Spectrograph.

The consortium responsible for the design and construction of the instrument includes the Universidad Complutense de Madrid (UCM, Spain) where the MEGARA Principal Investigator (Armando Gil de Paz) is located, the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE, México), the Instituto de Astrofísica de Andalucía (IAA-CSIC, Spain), and the Universidad Politécnica de Madrid (UPM, Spain). MEGARA is being developed under contract with GRANTECAN.

3. SYSTEM ENGINEERING TASKS

3.1 Requirements engineering

Requirements engineering is the System Engineering activity devoted to develop the system requirements. This activity starts identifying the high-level requirements to iteratively generate lower level requirements during the design and decomposition of the system.

In order to define the complete set of MEGARA high-level system requirements, the top-level science performance requirements has been collected as well as the environmental, production, operation, maintenance and handling constraints that could apply to the instrument and the GTC interfaces (focal stations constraints, services to the instruments, standards to be applied, etc.) applicable to MEGARA.

During the conceptual design, two documents were generated to gather this information:

- MEGARA Functional Requirement document, where the high-level scientific requirements (taking into account both the GTC and the MEGARA scientific group high-level needs) are defined.
- MEGARA Interface to GTC Requirement document, where all GTC interfaces, environmental, operation, maintenance and handling constraints are defined.

During the preliminary and detailed design, the MEGARA System Specification document was produced to specify the solution adopted for the MEGARA instrument. This document contains the lower level specifications of the MEGARA subsystem and components. The specified solution fulfills the requirements stated in the MEGARA Functional Requirement and MEGARA Interfaces to GTC documents; traceability to both documents was implemented.

In addition, the interface control documents between the MEGARA subsystems that are developed by different groups have been defined. All requirements, specification and interface documents are now under configuration control.

Following the best engineering practices, the requirements included in the documents mentioned in the previous paragraphs have been developed fulfilling the conditions identified in the following lines:

- The requirements must be identifiable (a unique code will be assigned).
- The source of the requirement must be identified (source or parent requirement).
- Each requirement must be unique (in order to facilitate the traceability of the requirement).
- The requirement must be concise and unambiguous.
- The technical requirements of the proposed solutions (i.e., specifications) must be verifiable.

Requirements are stored and managed by the FRACTAL Configuration Management Tool (GECO), which facilitates the traceability and control of the requirements. GECO enables to establish relationships between parent and children requirements and helps the System Engineering to analyze the impact of the Configuration Changes and Non-conformities that could be raised during system development. GECO allows automatically generating requirement documents and specifications from the requirements kept in the application.

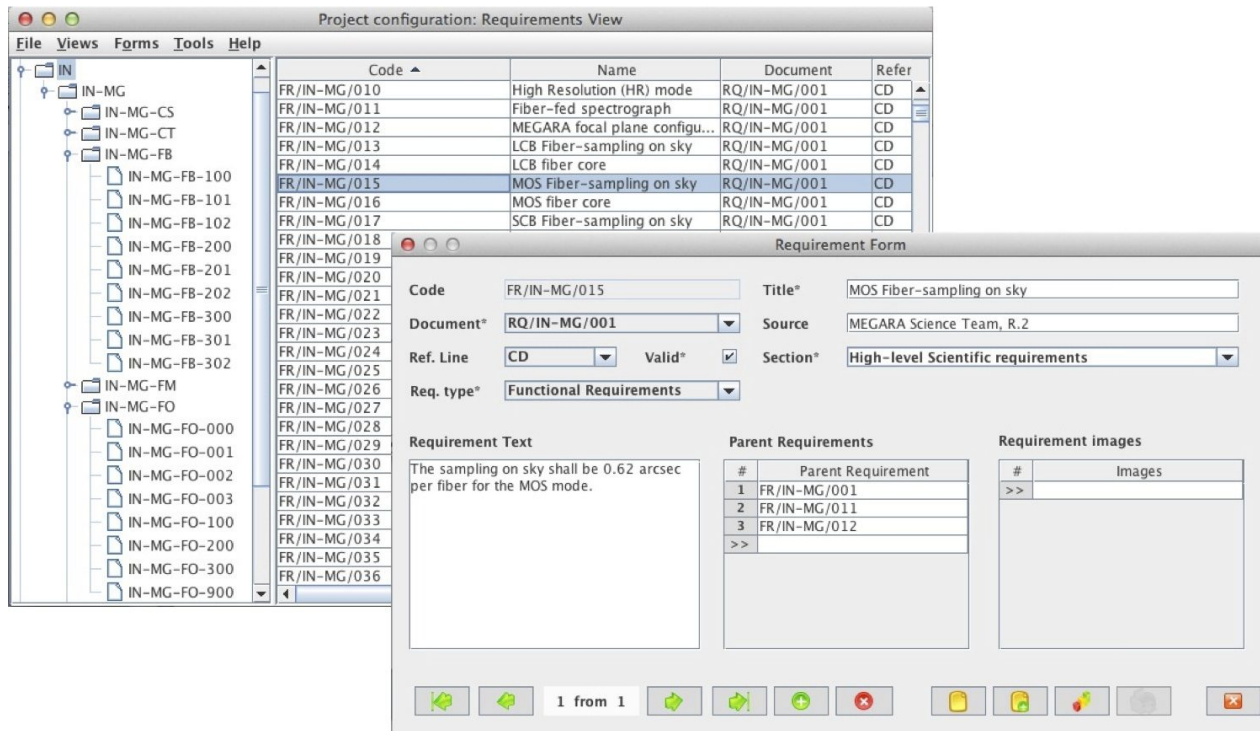


Fig. 2. MEGARA requirements list and form view at GECCO.

3.2 System technical budgets

Technical budgets must be defined and maintained for the main physical and functional parameters of the system. The control of the technical budgets is particularly important to facilitate system integration and to guarantee that the system reaches the required performances.

In order to develop them correctly, the following issues are being taken into account:

- Budgets and tolerances must be defined for each level of the system.
- The tolerances must be reduced during the system detailed design.
- A technical budget must be defined for each physical parameter of the system (i.e., mass, power consumption, thermal dissipation, etc.).
- The technical budgets must be verified.

In MEGARA, the following technical budgets are being produced and maintained:

- Image quality to determine the optical performance of the system.
- Spectral resolution and Spectral resolution repeatability to determine spectral resolutions deviations due to static contributors (such as misalignments and manufacturing errors of the subsystems) for the spectral resolution budget and to dynamic contributors (such as the spectrograph mechanism performance) for the spectral resolution repeatability.
- Image stability to determine the stability (in position) of the spectra projected on the detector during an observation.
- Spectral alignment and Spectral alignment repeatability to determine the displacement of the estimated position of the spectra at the detector for all resolution modes (LR, MR and HR, respectively) due to static contributors

(such as misalignments and manufacturing tolerances of the subsystems) and to dynamic contributors (such as the performance of the spectrograph mechanisms that could affect to the project spectra position).

- Throughput to determine the overall losses in the instrument since the light is received in the field lens until it reaches the detector.
- Flux homogeneity to determine the differences in flux between fibers (due to manufacturing and misalignments errors) in order to ensure a proper relative-flux calibration and cosmetics.
- Mass to identify the masses of all MEGARA components.
- Power consumption to identify the power consumption of the applicable components.
- Glycol water consumption to identify the glycol water consumption of the applicable components
- Thermal dissipation to identify the thermal dissipation of the active components.
- Reliability to identify the mean time between failures (MTBF) and mean time to repair (MTTR) of the applicable components.

ITEM	LR		MR		HR		ITEM	LCB mode	MOS mode	SCB mode
	Spatial y-axis	Spectral x-axis	Spatial y-axis	Spectral x-axis	Spatial y-axis	Spectral x-axis				
Pseudo slit alignment errors	± 3.3	± 10	± 3.3	± 10	± 3.3	± 10	Microholes position	±5 µm	±5 µm	±5 µm
Collimator and camera optical axis error	± 17	± 17	± 17	± 17	± 17	± 17	Microholes diameter (fiber centering)	±3.5 µm	±3.5 µm	±3.5 µm
Camera-Coll. angle	-	± 22	-	± 21	-	± 20	Microholes position	±5 µm	±5 µm	±5 µm
VPH lines per mm tolerance	-	± 60	-	± 60	-	± 74	Microholes diameter	±2 µm	±2 µm	±2 µm
Grating optics manufacturing and assembly tolerance	-	± 10	-	± 20	-	± 20	Microholes – fiber assembling and gluing	±5 µm	±5 µm	±5 µm
Grating alignment tolerance	± 1	± 4	± 1	± 3	± 1	± 2	Support frame assembling errors (static)	-	±1 µm	-
Detector alignment tolerance	± 6.6	± 6.6	± 6.6	± 6.6	± 6.6	± 6.6	MOS minibundles dynamic errors	-	±4.7 µm	-
TOTAL (pixels)	±19	± 68	± 19	± 70	± 19	± 82	TOTAL	±9.55 µm	±10.69 µm	±9.55 µm
Requirement (pixels)	±900	±100	±900	±100	±900	±100	Requirement	±10 µm	±10 µm	±8 µm

Fig. 3. Left: Spectral alignment error budget. Right: Flux homogeneity error budget.

3.3 System analysis

Different system analyses will be carried out during the complete system life cycle and at different level of decomposition of the system.

Functional analysis to study the functions that must be performed by a system and assign them to lower level and trade-offs to evaluate several alternatives and select the best one (according to the evaluation established criteria) could be required at different phases of the project.

Project analysis to evaluate that the project is fulfilling cost, schedule and technical objectives and risk analysis to identify and assess risks that could affect to the project development must be performed regularly as part of the quality control activities of the project. For project management control, MEGARA is using the FRACTAL Project Management Tool (MANATEE). The outputs of these analyses are included at MANATEE and at the MEGARA Project Management Plan.

System performance analysis must be done to evaluate the system performance and to assess the manufacturing and integration tolerances assigned to the different components. As mention in section 3.2, image quality, spectral resolution and spectral resolution repeatability, flux homogeneity, image stability, spectral alignment and spectral alignment repeatability analysis and throughput analyses have been performed to produce the system technical budgets.

The Reliability, Availability, Maintainability and Safety (RAMS) analyses have been also performed to ensure that MEGARA design meets the availability, reliability, maintainability and safety requirements imposed to the system.

- Maintainability Analysis analyzes how to maintain the system and to minimize and facilitate its maintenance during the operation phase.
- Handling and Transport Analysis ensures that the handling and transport constraints (as stated by GRANTECAN) are compiled and establishes the corresponding requirements in the MEGARA Interface to GTC document.
- Failure Analysis (FMECA) identifies and evaluates the potential failure modes of the system, subsystems and components.
- Reliability Analysis estimates the percentage of time that the system could be unavailable taken into account the failure modes identified at the FMECA.
- Spare analysis provides a recommended spare parts list taken into account the outputs from the FMECA's and reliability analyses.
- Safety Analysis identifies and assesses the hazards that could happen to the persons that are involved in the use and maintenance of the system.

Other important point to be mention is the use of simulation models, which provide support not only during the design phase but also during the verification of the system. These models are mainly used to facilitate trade-offs (e.g., to evaluate solution performances or the feasibility of the proposed solutions) and in the maintainability analysis (e.g., study access to the different components, analyze envelopes, etc.).

The following simulation models have been generated and being used at MEGARA:

- Optical Model (Zemax)
- Mechanical and thermal model (Ansys)
- 3D dimensional model (Pro-Engineer)
- Control System Simulator.

Additionally, a Fiber MOS positioner prototype to demonstrate manufacturability and a fiber minibundle prototype to perform preliminary measurement of the fibers transmission and FRD have been produced.

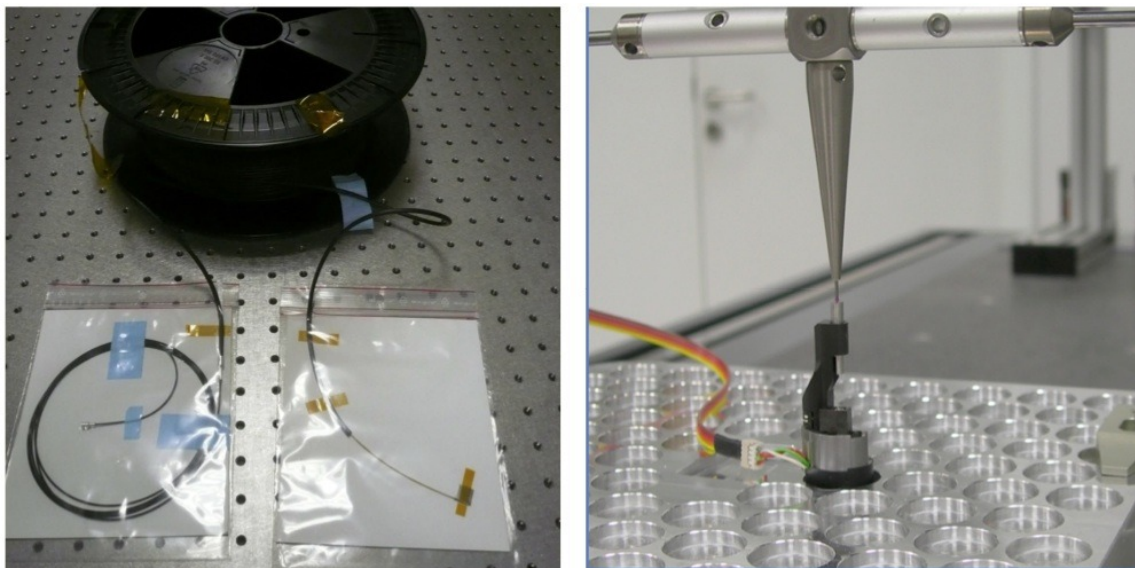


Fig. 4. Left: MEGARA fiber minibundle prototype. Right: Fiber MOS positioner at the measuring device.

3.4 Product tree

The Product Tree is the hierarchical breakdown of a system into low-level elements that fully define the system. The goal is to reach a level of division into discrete elements that can be produced independently. The Product Tree is produced as result of the design process.

Each element of the Product Tree must have a unique code. At MEGARA, this code is used for coding other elements such as drawings, requirements, interfaces, etc. The Product Tree code has been defined using the GTC configuration codification rules to facilitate later the integration of the instrument in the GTC system.

The Product Tree elements are registered in GECO, from where they can be exported to an excel sheet.

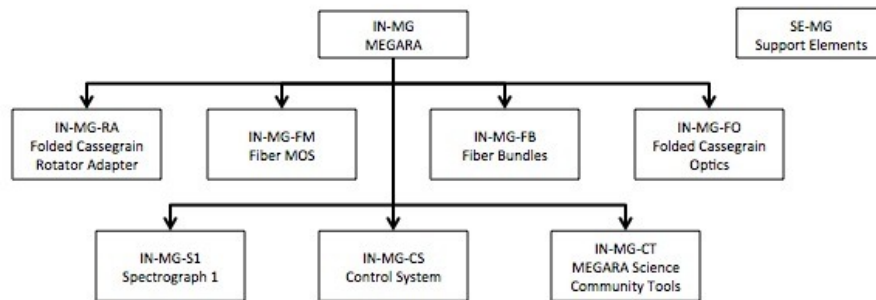


Fig. 5. MEGARA Product Tree elements at the first level.

Code	Name	Description
IN-MG-S1-500	Camera	The Camera includes the Optical and Opto-mechanical components to conduct the light from the pupil position to the Detector.
IN-MG-S1-510	Camera Optics	The Camera Optics include the Camera Optical components.
IN-MG-S1-511	CAM-D1 lens	CAM-D1/CAM-D2 doublet
IN-MG-S1-512	CAM-D2 lens	CAM-D1/CAM-D2 doublet
IN-MG-S1-513	CAM-D3 lens	CAM-D3/CAM-D4 doublet
IN-MG-S1-514	CAM-D4 lens	CAM-D3/CAM-D4 doublet
IN-MG-S1-515	CAM-S5 lens	
IN-MG-S1-516	CAM-S6 lens	
IN-MG-S1-517	CAM-S7 lens	
IN-MG-S1-520	Camera Barrel	The Camera Barrel refers to the barrel that supports the Camera Optics elements.
IN-MG-S1-521	Camera Outer Barrel Subassembly	
IN-MG-S1-521-001	Camera outer barrel	
IN-MG-S1-521-002	Camera titanium flexure	2 x
IN-MG-S1-521-003	M6x14 Stainless Steel cap screw	16 x M6x14 Stainless Steel cap screw - McMaster (92290A320)
IN-MG-S1-521-004	M4x16 Stainless Steel cap screw	32 x M4x16 Stainless Steel cap screw - McMaster (92290A154)
IN-MG-S1-521-005	M4x0.7 Stainless Steel Hex Locknut	32 x M4x0.7 Stainless Steel Hex Locknut - McMaster (94205A230)
IN-MG-S1-521-006	M4x8 Stainless Steel cap screw	32 x M4x8 Stainless Steel cap screw - McMaster (92290A140)
IN-MG-S1-521-007	M5x25 Stainless Steel cap screw	16 x M5x25 Stainless Steel cap screw - McMaster (92290A252)
IN-MG-S1-521-008	Camera outer barrel final ring	
IN-MG-S1-521-009	M5x14 Stainless Steel cap screw	16 x M5x14 Stainless Steel cap screw - McMaster (92290A230)
IN-MG-S1-521-010	Camera outer barrel initial ring	
IN-MG-S1-522	Camera Inner Barrel Subassembly	
IN-MG-S1-522-001	Camera inner barrel ring	
IN-MG-S1-522-002	Camera inner barrel	
IN-MG-S1-522-003	Camera inner barrel flange	
IN-MG-S1-522-004	M4x16 Stainless Steel cap screw	32 x M4x16 Stainless Steel cap screw - McMaster (92290A154)
IN-MG-S1-522-005	M3x6 Stainless Steel cap screw	12 x M3x6 Stainless Steel cap screw - McMaster (92290A111)

Fig. 6. MEGARA Product Tree elements detailed list partial view.

3.5 Interfaces

An interface is defined as the boundary between two subsystems or components (hardware or software) that are responsibility of two different groups of engineers (or contractors) that work separately.

The system interfaces may be external (with other adjoining systems) or internal (between subsystems). As mentioned in section 3.1, the MEGARA external interfaces (with GTC) are included in the MEGARA Interface to GTC Requirement document.

The internal interfaces must be identified and defined during the design process. The definition of the interfaces includes establishing and maintaining the interface table, defining the interface requirements (i.e., elaborating requirements documents for each identified interface) and maintaining interface control (as part of the configuration control).

The interfaces must be defined between physical components with the aim to minimize the amount of data that must be exchanged between components. This is particularly important from two points of view: to avoid complicating the communication between working groups and to facilitate system integration.

Code	Element1	Element2	Name	Description
IN-MG-S1-000/IN-MG-S1-400	IN-MG-S1-000	IN-MG-S1-400	Optical bench - Spectral Subsystem	INT/IN-MG-S1-000/IN-MG-S1-470/001 Support Structure - Spectral subsystem mechanism DR/IN-MG-S1/002 MEGARA Main subsystems positions at the optical bench DR/IN-MG-S1-400/001 MEGARA Spectral subsystem DR/IN-MG-S1/006 MEGARA Optical bench – Wheel interface DR/IN-MG-S1-479/000 MEGARA Insertion mechanism DR/IN-MG-S1/007 MEGARA Optical bench – Insertion mechanism interface
IN-MG-S1-000/IN-MG-S1-700	IN-MG-S1-000	IN-MG-S1-700	Optical bench - CCD Controller	INT/IN-MG-S1-000/IN-MG-S1-700/001 Support Structure - CCD Controller DR/IN-MG-S1/002 MEGARA Main subsystems positions at the optical bench DR/IN-MG-S1-700/000 MEGARA CCD Controller DR/IN-MG-S1/010 MEGARA Optical bench – CCD Controller interface
IN-MG-S1-040/IN-MG-S1-500	IN-MG-S1-040	IN-MG-S1-500	Camera-Cryostat Support Structure - Camera	INT/IN-MG-S1-040/IN-MG-S1-500/001 Camera-Cryostat Support Structure - Camera DR/IN-MG-S1-520/000 MEGARA Camera subassembly DR/IN-MG-S1-040/000 MEGARA Camera-Cryostat Support Structure DR/IN-MG-S1/008 MEGARA Camera-Cryostat Support Structure, Camera and Cryostat interface
IN-MG-S1-200/IN-MG-S1-300	IN-MG-S1-200	IN-MG-S1-300	Shutter - Collimator	INT/IN-MG-S1-200/IN-MG-S1-300/001 Shutter - Collimator DR/IN-MG-S1-210/000 MEGARA Shutter mechanism assembly DR/IN-MG-S1/004 MEGARA Shutter - Collimator interface
IN-MG-S1-400/IN-MG-S1-400	IN-MG-S1-400	IN-MG-S1-400	VPH Optics - VPH Opto-mechanics	INT/IN-MG-S1-400/IN-MG-S1-400/001 VPH Optics - VPH Optomechanics DR/IN-MG-S1-412/000 LR Opto-mechanics DR/IN-MG-S1-432/000 MR Opto-mechanics DR/IN-MG-S1-466/000 HR Opto-mechanics

Fig. 7. MEGARA Interface table partial view.

3.6 System verification

The system verification must include all activities that will be performed to ensure that the final system meets the initial high-level requirements.

MEGARA System and subsystems acceptance will be carried out at different levels. The subsystems will be firstly accepted at factory and, then, at the MEGARA integration laboratory (LICA, Laboratorio de Instrumentación Avanzada), which is located at the Universidad Complutense de Madrid (UCM). The whole system will be also firstly integrated and accepted at LICA and, finally, at GTC.

3.6.1 Verification matrices

In order to accept the system, subsystems and components, the verification matrix of each element must be prepared including all element requirements and identifying the corresponding acceptance activities.

GECCO facilitates the generation of the verification matrices by exporting the requirements of the selected elements to the matrix and also allows exporting the matrices to an excel table to be attached to the corresponding verification documents.

At the verification matrix, the following issues will be defined for each requirement:

- The verification method: testing, analysis, design review or inspection for each verification milestone.
- The verification procedure to be followed for verifying the requirement.
- The verification result to state the compliance or non-compliance of the requirement (in the later case, a non-conformity will be raised and identified at the matrix).
- The verification report, if needed, to add additional details about the verification results.

The full MEGARA verification matrix shall include all high-level system requirements, subsystems and low-level elements requirements and also interface requirements.

The screenshot displays the GECCO software interface for managing verification matrices. The main window, titled 'Project configuration: Verification Matrix View', features a tree view on the left showing a hierarchy of requirements (PT, IN, IN-MG, IN-MG-CS, IN-MG-CT, IN-MG-FB, IN-MG-FM, IN-MG-FO, IN-MG-RA, IN-MG-S1, IN-MG-S1-000, IN-MG-S1-010, IN-MG-S1-011, IN-MG-S1-012, IN-MG-S1-013, IN-MG-S1-020, IN-MG-S1-040, IN-MG-S1-050, IN-MG-S1-060, IN-MG-S1-070, IN-MG-S1-100, IN-MG-S1-110, IN-MG-S1-111, IN-MG-S1-112). The central table lists requirements with columns for Code, Name, Test Procedure, and Test. The 'Verification Matrix Form' window is open, showing details for requirement 'TR/IN-MG-FM/003' (Positioner patrol area). The form includes fields for Code, Title, Responsible (Arrillaqa, Xabier), Doer (Arrillaqa, Xabier), Planned Date (01-10-2014), Exec. Date (00-00-0000), Test procedure, Test report, Non-conform. (dropdown), and Comments. A 'Conform' checkbox is also present. The bottom of the form shows a status bar with '1 from 1' and various icons.

Code	Name	Test Procedure	Test
TR/IN-MG-FM-100/001	Fiber MOS positioner control...		
TR/IN-MG-FM-100/002	Positioner electronics master...		
TR/IN-MG-FM-100/003	Positioner electronics comm...		
TR/IN-MG-FM-100/004	Positioner voltage		
TR/IN-MG-FM-100/005	Positioner maximum consum...		
TR/IN-MG-FM-100/006	Positioner electronics low dis...		
TR/IN-MG-FM-300/001	Fiber MOS positioner low lev...		
TR/IN-MG-FM/001	Fiber MOS functionality		
TR/IN-MG-FM/002	Number of positioners		
TR/IN-MG-FM/003	Positioner patrol area		
TR/IN-MG-FM/004	Distance between adjacent ...		

Verification Matrix Form

Code: TR/IN-MG-FM/003 Title: Positioner patrol area

Responsible: Arrillaqa, Xabier Verification method: Test (see TEC/MEG/077)

Doer: Arrillaqa, Xabier

Planned Date: 01-10-2014 Verification result:

Exec. Date: 00-00-0000

Test procedure: Verific. milestones: Subsystem acceptance

Test report:

Non-conform.: Comments:

Conform: ☐

Fig. 8. GECCO Verification matrix requirements list and form.

3.6.2 Assembly, Integration and Verification (AIV) Plan

The MEGARA AIV Plan will include the scheduling of all activities to integrate the system and verify that it fulfills the initial requirements.

During the detailed design a preliminary version of the following documents have been already produced to identify the activities that shall be performed to assembly, integrate and verify each main subsystem:

- MEGARA. Fiber MOS acceptance tests and integration plan at AVS
- MEGARA Optical Fibers: Fibers and microlenses characterization, assembly and tests
- MEGARA Optics: Testing Plan at INAOE and CIO
- MEGARA Optics: Manufacturing Plan at INAOE and CIO
- MEGARA Cryostat Integration Plan
- MEGARA Cryostat acceptance tests at INAOE
- MEGARA Cryostat acceptance tests at LICA
- MEGARA Detector characterization: Test bench and prototype system
- MEGARA Detector Integration and Assembly Test Plan
- MEGARA Detector Characterization Test Plan
- MEGARA Spectrograph Integration Plan
- MEGARA Spectrograph Mechanisms Acceptance Tests
- MEGARA Camera and Collimator Opto-mechanics Integration and Verification Plan
- MEGARA Spectrograph. Pupil elements tests at LICA
- MEGARA Spectrograph Integration at LICA and setup

Besides the preliminary versions of the following AIV system level documents have been also produced:

- MEGARA system verification at LICA, which includes the verification activities to demonstrate that MEGARA is fulfilling the high-level requirements before being shipped to GTC.
- MEGARA Integration and Verification Plan, which summarizes all the activities that shall be done at subsystem level to accept each subsystem (as identified in the document list above), to integrate the whole instrument and to verify it at LICA.
- MEGARA Instrument Integration on Site, which contains the Integration Plan of MEGARA at GTC.
- MEGARA Commissioning plan, which contains the MEGARA Commissioning plan at GTC.

The AIV procedures must include the detailed description of the activities to be done, identifying tools, manpower, conditions to be met, the execution environment and any other relevant information that must be needed to execute and plan the activity.

The integration and verification activities to be performed at GTC during the commissioning of the instrument will be further elaborated following the GRANTECAN directions and constrains (i.e., taken into account the time and resources allocated to the MEGARA commissioning).

The MEGARA AIV Plan will be included and controlled using MANATEE, as the rest of tasks of the MEGARA Project Management Plan.

3.7 Configuration, non-conformities and anomalies control

All configuration elements of the system must be under configuration control. The configuration elements include the Product Tree, interfaces, requirements, specifications documents and drawings. Any change request affecting these elements shall be treated as a configuration change.

In addition, during the execution of the integration and verification activities, non-expected behaviors may appear, which would be treated as anomalies (to describe bugs or problems) or non-conformities (to describe the non-compliance of a requirement).

Project procedures have been defined to establish how to manage configuration changes, non-conformities and anomalies at the MEGARA project.

MEGARA Systems Engineer will be responsible to implement and manage the configuration control and also will assume the Product Assurance role being responsible to analyze the anomalies and non-conformities that may occur during the integration and test phases.

All will be stored at GECCO, which provides the capabilities to facilitate the analysis that must be done and to track them.

Fig. 9. GECCO Configuration change form.

Fig. 10. GECCO Non-conformity form.

3.8 Operation and maintenance plan

MEGARA operation shall be part of the GTC operation plan. As a facility instrument MEGARA must define the observing modes that will offer, including science and calibration modes, and the recommended calibration plan to obtain the best scientific return of the observations to be performed. This information is already included at the MEGARA Observing Modes and MEGARA Calibration Plan documents.

The MEGARA Maintenance Plan must include all the activities that must be carried out in order to ensure that the instrument is maintained in good working conditions and is ready to be used during the night observations. The MEGARA Maintenance Plan will be generated during the following phases in agreement with the GTC Maintenance Plan and the maintenance policy stated by GRANTECAN.

4. CONCLUSIONS

This article describes the system engineering activities that are being performed at the MEGARA project in order to ensure that the instrument shall fulfill the scientific requirements and project constraints.

MEGARA is now entering at the manufacturing and AIV phases. The system design is fixed and under configuration control. From the system-engineering point of view, the next steps are to prepare the detailed versions of the verification matrices and AIV procedures at subsystem and system level while keeping the technical control of the project.

REFERENCES

- [1] Gil de Paz, A. et al. "MEGARA: a new generation optical spectrograph for GTC", Proc. SPIE 9147, (2014)
- [2] García-Vargas, M.L. et al. "Project Management for complex ground-based instruments: MEGARA plan", Proc. SPIE 9150, (2014)