Programme: **ELT**

Project: **ELT MCAO Construction – MORFEO**

# LGS WFS camera requirements

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## Sommario

# 1 Related Documents

## 1.1 Applicable Documents

**MAO-PFE-1.6 Applicable documents**

The following documents, of the exact version shown, form part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the content of this document, the content of this document shall be considered as superseding the others.

AD1 EN-61010-1 Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements;

AD2 EN-60332-1 Tests on electric and optical fibre cables under fire conditions;

AD3 ESO-044295 Electrical and Electronic Design Standards;

AD4 ESO-192984 ESO Mechanical Standards;

AD5 ESO-193497 SAF-GEN-MAN-3444 ESO Safety Conformity Assessment Procedure;

AD6 ESO-262869 ICD between the E-ELT SCPs and the SCP Clients;

AD7 ESO-305615 Common ICD between CCS/ICS and Detector Control System (DCS);

AD8 ESO-310635 ELT Instrument Adaptive Optics Real-Time Computer - Real-Time MUDPI Stream Protocol;

AD9 ESO-312673 ELT Instrument Adaptive Optics Real-Time Computer - Wavefront Sensor Detector Controller Requirements Specification;

AD10 ESO-320983 ICD between the Network Equipment and its Clients;

## 1.2 Reference Documents

RD1 IEEE 802.3-2009 Telecommunications and information exchange between systems – Local and metropolitan area networks – Part 3;

RD2 ISO/IEC 24702 Information technology — Generic cabling — Industrial premises;

RD3 IEEE 1588-2008 Precision clock synchronization protocol for networked measurement and control systems;

RD4 IETF RFC 791 Internet Protocol;

RD5 ESO-232766 Technical Specification of the E-ELT Service Connection Points;

RD6 ESO-310063 Technical Detector Control Software for COTS Cameras - User Manual;

RD7 ESO-319695 ELT ICS Framework - Technical Control Software - TCCS - User Manual;

RD8 ESO-321432 Electronic Product Marking for ELT;

RD9 SFF 8431 Specifications for Enhanced Small Form Factor Pluggable Module SFP+;

RD10 IEEE 802.3-2009 Telecommunications and information exchange between systems – Local and metropolitan area networks – Part 3;

RD11 IETF RFC 768 User Datagram Protocol;

RD12 IETF RFC 1122 Requirements for Internet Hosts;

# 2 Introduction

## 2.1 Scope

MORFEO (formerly known as MAORY) is the Adaptive Optics Module for ELT.

This document contains the requirement specifications for the cameras of the LGS WFSs.

This document contains requirements that have to be fulfilled by the device being procured and that have to be verified by the Vendor.

## 2.2 Naming Convention

Requirements are identified with a requirement tag enclosed into squared brackets [], each tag is unique.

## 2.3 Abbreviations and Acronyms

| | |
|---|---|
| AC | Alternating Current |
| AD | Applicable Document |
| AO | Adaptive Optics |
| API | Application Programming Interface |
| ARR | Acceptance Readiness Review |
| CCD | Charge Coupled Device |
| CII | Core Integration Infrastructure |
| CMOS | Complementary Metal Oxide Semiconductor |
| CNRS | Centre National de la Recherche Scientifique |
| COTS | Commercial Off-The-Shelf |
| DER | Design Report |
| ELT | Extremely Large Telescope |
| EM CCD | Electron Multiplying CCD |
| ESO | European Southern Observatory |
| FDR | Final Design Review |
| FoV | Field of View |
| HW | Hardware |
| IAA | Instrument Assembly Area |
| ICD | Interface Control Document |
| ICH | Instrument Control Hardware |
| ICS | Instrument Control System |
| ICSS | Instrument Control System Software |

| | |
|---|---|
| INAF | Istituto Nazionale di AstroFisica |
| INS | Instrumentation Software |
| INSU | Institut National des Sciences de l'Univers |
| IORR | Instrument Operations Readiness Review |
| IPAG | Institut de Planétologie et d'Astrophysique de Grenoble |
| I-PXX/PFE | Interface between PXX subsystem and DMs subsystem |
| IR | Infrared |
| IRD | Interface Requirement Document |
| IWS | Instrument Workstation |
| LCI | Local Communication Infrastructure |
| LCS | Local Coordinate System |
| LGS | Laser Guide Stars |
| LOR | Low Order and Reference |
| LRU | Line Replacement Units |
| M11M | Mirror 11 MORFEO |
| MAIT | Manufacturing Assembly Integration and Test |
| MCAO | Multi Conjugate Adaptive Optics |
| MCMT | Maximum Corrective Maintenance Time |
| MDT | Mean Down Time |
| MICADO | Multi-AO Imaging Camera for Deep Observations |
| MOI | Moment of Inertia |
| MORFEO | Multi conjugate adaptive Optics Relay For ELT Observatory |
| MTBF | Mean Time Between Failures |
| N/A | Not Applicable |
| NGS | Natural Guide Star |
| NP | Nasmyth Platform |
| NUIG | School of Physics at the National University of Ireland Galway |
| OAA | Osservatorio Astrofisico di Arcetri |
| OAAB | Osservatorio Astronomico d' Abruzzo |
| OAB | Osservatorio Astronomico di Brera |
| OACN | Osservatorio Astronomico di Capodimonte |
| OAPD | Osservatorio Astronomico di Padova |
| OAS | Osservatorio di Astrofisica e Scienza dello Spazio di Bologna |
| PAC | Preliminary Acceptance Review in Chile |
| PAE | Preliminary Acceptance Europe |
| PDR | Preliminary Design Review |
| PDR | Preliminary Design Review |
| PFE | MORFEO M11subsystem |
| PFS | Primary Focal Station |
| PH0 | MORFEO Instrument control Electronics Subsystem |
| PI | Principal Investigator |
| PLC | Program Logic Controller |
| PM | Project Manager |
| PM0 | MORFEO Main Support Structure Subsystem |
| PR0 | MORFEO RTC subsystem |
| PSF | Point Spread Function |
| PSO | MORFEO Software subsystem |
| PT | Product Tree |
| PT0 | MORFEO Thermal control subsystem |
| PTP | Precision Time Protocol |
| RAMS | Reliability, Availability, Maintainability and Safety |
| RBM | Rigid Body Motion |

| | |
|---|---|
| RD | Reference Document |
| RMS | Root Mean Square |
| RoHS | Restriction on Hazardous Substances |
| RON | Read Out Noise |
| RTC | Real-Time Computer |
| SAT | System Architect Team |
| SCAO | Single-conjugate Adaptive Optics |
| SCS | Standard Coordinates System |
| SDK | Software Development Kit |
| SE | System Engineer |
| SET | System Engineering Team |
| SMR | Spherical Mounted retroreflector |
| SMU | Sensor Monitor Unit |
| SOW | Statement of Work |
| SR | Strehl Ratio |
| SRR | System Requirements Review |
| SRS | Standard Reference System |
| SW | Software |
| TBC | To Be Confirmed |
| TBC | To Be Clarified |
| TBD | To Be Defined |
| TBD | To Be Defined |
| TBW | To Be Written |
| TC | Technical Camera |
| TCCD | Technical CCD |
| TCCS | Technical Camera Control Software |
| TCP | Transmission Control Protocol |
| TDCS | Technical Detector Control Software |
| TP | Temperature Probe |
| UDP | User Datagram Protocol |
| USB | Universal Serial Bus |
| VLT | Very Large Telescope |
| WFS | Wavefront Sensor |
| WP | Work Package |
| WS | Workstation |

# 3 Product Description

## 3.1 MORFEO overview

ELT (Extremely Large Telescope) is the world's largest telescope (39m diameter) under construction by ESO (https://elt.eso.org/) at Cerro Armazones in Chile. ELT is considered worldwide to be one of the highest priorities in ground based astronomy. MORFEO

(http://wwwMORFEO.oabo.inaf.it/), as a first generation ELT instrument, will help compensate for the distortion of light caused by turbulence in the Earth's atmosphere. MORFEO is a Multi-Conjugate Adaptive Optics (MCAO) module that will allow spatially uniform adaptive optics compensation over a large field of view (up to 2 arcmin$^2$) with high sky coverage. Wavefront sensing is performed by six Laser Guide Stars (LGS) and three Natural Guide Stars (NGS), for the measurement of high and low-order wavefront perturbations respectively

## 3.2 The cameras of the LGS WFS

The LGS Wavefront sensor measures the perturbation of the wavefront looking at the so called Laser Guide Stars which are bright light spot created in the atmosphere exploiting the back emission of the sodium layer at about 90 km altitude. The sodium layer is excited by means of a laser at 589nm wavelength. The sensor measures the perturbation of the wavefront taking many simultaneous images of the artificial source by means of a matrix of micro-lenses optically positioned in the pupil of the telescope. The images acquired by the cameras of each WFS is thus a collection of small spots each of which is the LGS image obtained by a micro-lens which defines a sub-aperture on the pupil. The camera shall continuously acquire images at a frame rate rate of about 500Hz.

# 4 Requirements

## 4.1 Environmental Conditions

**[R-STC-300]**

Verification: Test

The Camera shall be compliant with the environmental conditions in Table 1.

These are the typical environmental conditions during MAIT, Transport and Operations on the mountain. Operational conditions are those under which the Camera shall meet all its requirements. Functional conditions are those under which the Camera shall still be fully functional albeit not necessarily meeting all the requirements. Survival conditions are occasional (2-5 times within 10 years) conditions that may be experienced by the Camera during its lifetime, in such cases:

- the Camera shall survive such events and shall be able to restart operation after their occurrence;
- no damage of the Camera is allowed;
- all the functional and performance requirements defined in the present document shall still be met after actions taken as defined in the User Manual agreed with the customer.

Note: In the case the camera is not specified for condensing conditions, information about its vulnerability to it shall be provided as much as possible as, for instance, the presence of ventilation slots in the housing or insulating painting on the electronics boards inside.

| | Operational | Functional | Survival |
|---|---|---|---|
| **Air Pressure [mbar]** | 660 – 1000 | | |
| **Air Temperature [degC]** | 0 to +25 | -5 to + 25 | -10 to + 30 |
| **Vibrations [micrometre rms]** | 1 – 25 Hz: 1.4<br>25 – 50 Hz: 0.1<br>50 – 100 Hz: 0.25 | N/A | N/A |
| **Air Temperature gradient [degC / hour]** | -0.55 to +0.5 | -1.0 to +1.4 | -10.0 to + 10.0<br>(over 30 minutes) |
| **Relative Humidity [%]** | 5 to 80 | | 3 to 100,<br>with condensation |
| **Earthquake acceleration [g]** | N/A | | ax = +/-3.6<br>ay = +/-3.6<br>az = +/-3.6<br>quasi-static |

Table 1: Environmental Conditions for the Camera.

**[R-STC-172]**

Verification: Test

The Camera in its transport box shall withstand the transport conditions in Table 2.

Survival conditions are conditions that may be experienced by the Camera during transport. The Camera shall survive such events and shall be able to restart operation after their occurrence:

- no damage of the Camera is allowed;
- all the functional and performance requirements defined in the present document shall still be met after actions taken as defined in the User Manual agreed with the customer.

| | Survival |
|---|---|
| **Gravity Orientation [relative to z-axis]** | As specified in packing requirements |
| **Air Pressure [mbar]** | 570 to 1045 |
| **Air Temperature [degC]** | -33 to +60 |
| **Relative Humidity [%]** | 3 to 100, with condensation |
| **Shipping vibration loads** | As defined in Figure 1 |
| **Mechanical shocks** | Drop height 20cm |

Table 2: Environmental Conditions for the Cameras during transport.

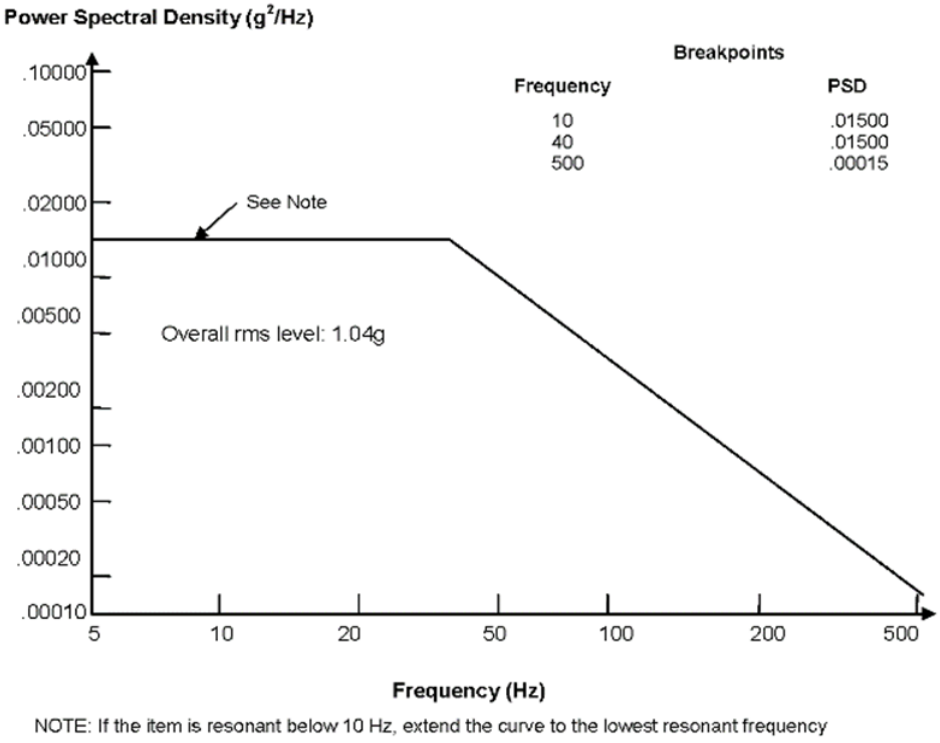


Figure 3: Power spectral density of accelerations applicable to transport.

## 4.2 Operational

**[R-STC-169]**

Verification: Test

The Camera shall support a Stand-By mode, where the Camera is powered, has reached its optimal and stable temperature, and is configured ready for operation.

**[R-STC-170]**

Verification: Test

The Camera shall support a Science Operation mode, where the Camera is powered, configured, and delivering images, and meeting its performance requirements.

**[R-STC-171]**

Verification: Test

The Camera shall support an Engineering mode, where the user has access to more settings of the Camera, than in the Science Operation Mode. This mode is required during the phases of maintenance, testing and optimization of the Camera's performance.

## 4.3 Interfaces

### 4.3.1 Network interfaces

**[R-STC-359-F]**

Verification: Design

For cameras with two optical network interfaces, one of them shall be dedicated to the pixel stream, whereas the other shall carry the aggregated control & PTP communications channel

For cameras with a single optical interface, all three communication channels shall be aggregated into a single physical interface.

**[R-STC-205]**

Verification: Inspection

The Communication Interface shall consist of up to two 1 or 10 Gigabit Ethernet (GbE) physical network interfaces compliant with the following specifications:

- Physical layer:
  - 1000BASE-T,
  - 1000BASE-LX,
  - 1000BASE-LH,
  - 10GBASE-LR,
  - 25GBASE-LR, or
  - 40GBASE-LR4, as per RD1
- Connector type:
  - Lucent Connector (LC), as per RD2
  - or RJ45 Connector

**[R-STC-205-F1]**

Verification: Inspection

When compatible with dimensional, power, heat dissipation, etc. constraints, the camera Data Interface shall support the deployment of pluggable network transceivers compliant with the following specifications:

· Enhanced Small Form Factor Pluggable (SFP+) Module, as per RD9.

**[R-STC-205-F2]**

Verification: Design

The camera Data Interface shall comply with the following standards:

· Ethernet, as per RD10.

**[R-STC-226]**

Verification: Test

All cameras shall have distinct Media Access Control (MAC) Addresses, with a format according to AD10. The MAC address of the sender shall be included in the Ethernet header. If the source MAC address is private, it shall be configurable at deployment time and its format shall be according to AD10.

**[R-STC-356]**

Verification: Test

The MAC address of the destination of the packet shall be resolved at runtime using the ARP protocol.

The format of the multi-cast destination MAC address shall be according to AD10.

**[R-STC-219-F4]**

Verification: Test

The camera Data Interface shall comply with the following requirements for internet host from RD12:

- Address Resolution Protocol (ARP)
- Internet Control Message Protocol (ICMP) ping sub-protocol

**[R-STC-214]**

Verification: Test

The Maximum Transmission Unit (MTU) of the camera Data Interface shall be 9,000 bytes.

**[R-STC-233]**

Verification: Test

The MTU shall be configurable in the camera, at a minimum at deployment-time.

**[R-STC-213]**

Verification: Test

The camera Data Interface shall comply with the following standards:

- Internet Protocol version 4 (IPv4) multicast, as per RD4.

**[R-STC-215]**

Verification: Test

Data transmission using both IP unicast and IP multicast shall be supported.

**[R-STC-229]**

Verification: Test

The following IP header fields shall be configurable in the camera:

• Source IP Address: IPv4 address of the sender of the packet. This field shall be configurable at run-time, before the camera becomes ready for image pixel data transmission.

• Destination / MultiCast IP Address(es): IPv4 address(es) of the receiver(s) of the packet. This field shall be configurable at run-time, before the camera becomes ready for image pixel data transmission.

• Netmask,

• Default gateway,

The Time-to-live (TTL) shall be either configurable to a value of between 1 and 255 (with a default value of 128), or it shall be set to a fixed value of 128.

**[R-STC-231]**

Verification: Test

The following IP header fields shall be set to pre-defined values by the camera: don't Fragment (DF) Flag, (bit 1 of the Flags field in the IP header). It shall be set to 1, such that, if fragmentation is required to route the packet by intermediate equipment, it will be dropped.

**[R-STC-219-F3]**

Verification: Design

The camera Data Interface shall comply with the following standards:

· User Datagram Protocol (UDP), as per RD11

**[R-STC-357]**

Verification: Test

The camera shall allow to disable retransmission of packages in case of package loss.

**[R-STC-71-F]**

Verification: Test

The output data streaming shall implement the RTMS/MUDPI protocol as specified in AD8. A detached device (adapter), external to the camera head, that converts the data format is acceptable as long as the full protocol and all related requirements specified in AD8 are implemented. In such case this adapter will be considered an integrating part of the camera and any reference to the camera in this document will include it.

### 4.3.2 Mechanical interfaces

**[R-STC-81]**

Verification: Design

Custom build devices (incl. COTS products, which require hardware modification in addition to their standard specification), shall be designed and implemented in accordance with ESO mechanical standards, as defined in AD4.

**[CAM-8]**

Verification: Test

The Camera Head mass shall be less than 2.5 kg excluding coolant and cables.

**[CAM-9]**

Verification: Inspection

The camera shall fit into the following volume: 250 x 80 x 100mm (L x w x h). This includes the connectors attached to the camera, but this excludes the cables connected to the camera.

**[CAM-9b]**

Verification: Inspection

The camera shall have a reference mounting surface in its front surface where the entrance window is located. The mounting surface shall provide a minimum of four screw holes, the size and location of which shall be defined in an interface document provided by the manufacturer.

**[CAM-9c]**

Verification: Design

The mounting surface shall have a surface finish of better than Ra 1.6 and a

flatness of < 20µm PTV.

**[CAM-10]**

Verification: Inspection

The Camera head shall have all connections coming out through the back surface of the camera

**[CAM-11]**

Verification: Inspection

The cover of the Camera's head housing shall not use any glues or sealants that prevent them from being easily removed for inspection or to repair internal components and to be re-installed. "O" rings if used shall be Viton (FKM).

Advice: screws should be used to seal and fix the covers of the housing.

**[CAM-16]**

Verification: Test

The vibration imparted by the camera head to the mounting points shall be less than 0.5 µm rms (combined over all three axes) from 1-100 Hz.

**[CAM-16b]**

Verification: Inspection

The camera Eigenfrequency, without cables, shall be specified if available

**[CAM-21]**

Verification: Design

The alignment accuracy of the detector, with respect detector centre, shall be:

Linear:

- within a circle of radius 0.5mm on the detector plane
- +/-0.5mm on the direction orthogonal to the detector plane

Rotational:

- 2° detector plane clocking
- 1° angle between optical axis and detector plane normal

**[CAM-22]**

Verification: Test

The detector's optical surface shall not move w.r.t. mounting points with varying external (ambient) temperature between 0°C and 15°C by more than 1µm/K.

Keeping the camera at any fixed temperature within the specified working range, the detector's optical surface shall not move w.r.t. mounting points, by more than 1µm.

### 4.3.3 Thermal and chilling interfaces

**[CAM-12]**

Verification: Design

In the case it is needed to remove heat form the camera, it shall be liquid cooled. Air cooling is forbidden: no fan or heat sink are allowed on the camera head

**[CAM-13]**

Verification: Test

The Camera cooling circuit shall be leak proof. Coolant circuit shall sustain a pressure of 10 bar and shall be tested at 11 bar for at least 1 hour.

**[CAM-14]**

Verification: Design

Parts which get in contact with the cooling fluid specified in R-COL-251 and R-COL-254 shall be made of stainless steel or of aluminium alloys series 6000

**[CAM-15]**

Verification: Test

The Camera shall meet all requirements for a coolant temperature between -8ºC and 15ºC

**[CAM-17]**

Verification: Test

The Camera head shall be able to operate and meet all requirements at a coolant flow rate of maximum 2 l/min.

**[CAM-18]**

Verification: Test

The coolant inlet-outlet temperature maximum drop shall be <= 1ºC.

**[CAM-19]**

Verification: Test

With the chilling fluid at ambient temperature T, the camera head external surfaces temperature shall not exceed the temperature range from T to T+5ºC .

**[CAM-20]**

Verification: Test

The average heat dissipation of the Camera Head shall not exceed 60W

### 4.3.4 Electrical interfaces

**[R-STC-55]**

Verification: Design

The camera shall comply with the ESO electrical standards requirements reported AD3

**[R-STC-52]**

Verification: Inspection

The camera shall be supplied with a Certificate of Conformance (CoC), signed by the manufacturer, supported by an accredited test house or facility, stating that the camera conforms to applicable International Standards and the EMC directives "Electrical equipment for measurement, control, and laboratory use" according to EN 61326:2013. The camera shall bear the CE mark based on this norm.

**[R-STC-177]**

Verification: Inspection

The Camera head shall have a dedicated electrical ground connection.

**[CAM-28]**

Verification: Design

A subsystem electrical cabinet is foreseen to host cameras power supplies (as per requirement [CAM-29]) and any possible adapter (as per requirement [CAM-27]). The cable length from the camera head to the subsystem cabinet shall be 10 m.

**[CAM-27]**

Verification: Test

In case an adapter device, external to the camera head, is developed to convert the output data stream format to the RTMS protocol, this device will be installed in the subsystem electrical cabinet. A provision for 3U space (19” standard box with 300mm depth) in the cabinet is foreseen to host adapters. Each adapter is expected to serve 2 cameras. The maximum electrical power absorption allowed for each adapter is 40W and the maximum thermal power dissipation is 40W

**[CAM-29]**

Verification: Design

The camera head should be powered by a low emission and low noise AC/DC-Converter power supply as Kniel CAA 24.5 or similar to be agreed between camera the provider and the customer. The power supply will be hosted in the subsystem electrical cabinet

**[CAM -30]**

Verification: Inspection

All the required cabling between the camera head and the electronics hosted in the subsystem electrical cabinet (power supplies and possible adapters) shall be provided together with the camera and their length shall be in accordance with [CAM-28]

### 4.3.5 Optical interfaces

**[DET-1]**

Verification: Test

The detector shall be the IMX425 monochrome chip 1608x1104 effective pixels by SONY and all requirements shall be fulfilled on an area of at least 1100x1100 contiguous pixels centred on the detector ±10 pixels on the longest dimension

**[DET-14]**

Verification: Designa/Test

Read-out scheme shall be global shutter.

**[CAM-23]**

Verification: Design

The Camera shall have a clear aperture of a diameter of at least 18 mm

**[CAM-24]**

Verification: Inspection

The aperture of camera head housing shall be closed by a window

**[CAM-25]**

Verification: Test

The entrance window shall comply with the following optical characteristic, met for unpolarised light and over the clear aperture, unless otherwise specified:

• flat window with no optical power;

• transmitted wavefront error < 40 nm rms measured with the window installed in its reference plate (>Ø17.5mm) -

• wedge <1 arcmin;

• the surface quality of the coated window shall be Scratch and Dig 20/10

**[CAM-25b]**

Verification: Inspection

The window shall be parallel to the contact surface of the mounting reference plane to within 1° PTV.

**[CAM-26]**

Verification: Test

The entrance window transmission shall be > 99% at wavelength range from 570 nm to 620 nm

**[CAM-32]**

Verification: Test

The camera shall not emit any light between 0.4 and 2.5 µm.

### 4.3.6 Other interfaces

**[R-STC-324]**

Verification: Design

The camera shall not use an USB communication interface, neither externally nor internally.

## 4.4 Functional Requirements

**[R-STC-182]**

Verification: Test

The camera shall acknowledge all user commands.

**[R-STC-183F]**

Verification: Test

The camera shall enable the end-user to modify all its configuration parameters, which are needed for operations, debugging, error identification, testing and maintenance. The meaning and operational ranges for all configuration parameters shall be provided. Parameters and/or combination of parameters whose setting could result in detector damage shall be clearly identified together their dangerous range of adjustment.

**[R-STC-184]**

Verification: Test

The camera shall provide a means for configuration data to be read.

**[R-STC-195]**

Verification: Test

The environmental parameters including detector, cooling block and electronics temperature, Peltier power, Camera head's pressure and humidity (as applicable) shall be able to be monitored.

**[R-STC-161-F1]**

Verification: Test

The camera shall use the Precision Time Protocol (PTP) according to RD3, to synchronize the internal reference clock with absolute precision better than 5 micro-seconds (goal 1 micro-second).

**[R-STC-161-F2]**

Verification: Test

The camera shall have the capability to schedule exposures and to set time stamp of frames based on the internal PTP disciplined clock.

**[R-STC-219-F2]**

Verification: Test

The Extended Info field of the leader packet defined in AD8, shall report a 64-bit, double precision, floating-point time stamp, expressed in seconds since UNIX epoch, following TAI timeline. It shall contain the closest time to the start of readout of the first camera region exposed in the data sample.

**[R-STC-248]**

Verification: Test

Each individual detector image transmitted by the camera shall be tagged with a monotonically increasing counter:

• The frame counter shall be written by the camera in the Sample-Id field of the RTMS/MUDPI protocol header.

• The frame counter value shall be incremented by 1 by the camera for each new detector image being transmitted.

• The counter value for the first detector image produced after the camera readout is started shall be 1.

• The counter value 2^32 - 1 shall roll over onto value 0.

If the camera is not able to fulfil this requirement, it shall be declared to the customer and an alternative strategy to tag images with a counter shall be agreed.

**[R-STC-251]**

Verification: Test

The camera shall time-stamp the start of each detector image readout and write the result in the Extended Info field of the leader packet (RTMS/MUDPI) of the corresponding detector image.

**[R-STC-253]**

Verification: Test

The camera shall time-stamp the start of transmission of each individual RTMS/MUDPI packet within a detector image and write the result in the Timestamp field of the RTMS/MUDPI protocol header.

**[R-STC-254]**

Verification: Test

Within each detector image, it shall be acceptable that the camera derives the per-packet time-stamps in [R-STC-251] by combining the per-image time-stamp in [R-STC-251] with a non PTP-corrected, internal clock (e.g. a timer that reset with the start of each detector image readout).

If this approach is taken, the time-stamping resolution in [R-STC-278] shall be applicable. In addition, the drift of the Camera internal clock within an individual detector image transmission shall be less than 1 micro-second.

**[R-STC-278]**

Verification: Test

The absolute time-stamping error in respect of [R-STC-251] and [R-STC-253] shall be smaller than 5 micro-seconds (goal 1 micro-second).

**[R-STC-279]**

Verification: Test

Within any detector image, the intra-image time-stamping error drift in respect of [R-STC-251] and [R-STC-253] shall be smaller than 1 micro-second.

If the time-stamping of individual RTMS/MUDPI packets in [R-STC-253] makes direct usage of an internal, PTP-corrected clock, requirement [R-STC-279] will pose constraints on the short-term stability of this clock's accuracy (e.g. limit the maximum PTP correction that may be applied to it during the transmission of a detector image).

Note:

Other compliant solutions are also possible. For example, the camera may derive the per-packet time-stamps in [R-STC-253] by combining the PTP-corrected, per-image time-stamp in [R-STC-251] with a low-drift, non PTP-corrected, internal timer that is reset with the start of each detector image readout.

**[R-STC-281]**

Verification: Test

The camera time-stamping convergence time to the absolute error band defined in [R-STC-251] shall be less than 2 minutes when a PTP sync interval smaller or equal than 1 s is used.

**[R-STC-319]**

Verification: Test

The quality and precision of the time synchronization of the camera with respect to the grand master clock shall be available among the other supervision data readable form the camera.

**[R-STC-315]**

Verification: Test

The camera shall provide a quality flag in the pixel stream (to indicate errors, over-temperature, etc.). If not available in the camera, and in case of critical errors, the camera shall stop the transmission of the pixel stream.

This error reporting mechanism shall be complementary (i.e. shall not replace) to any counterpart error communication channel between the camera and the supervising application.

**[R-STC-198]**

Verification: Test

Upon detection of an out-of-range condition, the camera shall issue a software alarm and, if severe, a hardware alarm.

**[CAM-1]**

Verification: Test

Camera turn-on time: the time required from power-off state to reach stand-by state (ready to start images acquisition) after switch-on shall be < 10 minutes including all camera configurations and detector cooling down if needed.

**[CAM-2]**

Verification: Test

Camera set-up time: the time needed to modify and apply any internal configuration of the camera or of the detector shall be < 5 sec after which the camera shall be ready to (re-)start images acquisition

**[CAM-3]**

Verification: Test

The camera shall enable the user to select regions of interest of at least 1100x1100 contiguous pixel to be continuously streamed in real time from the output port accordingly with scheduling timing requirements [R-STC-161-F2][R-STC-161-F3] [CAM-5][CAM-6].

**[CAM-4]**

Verification: Test

Data packing: pixel data shall be packet so that 2 pixels data (digitized at 12 bit each as per [DET-17]) are packet into 3B of data.

**[DET-17]**

Verification: Test

Digitisation of image data shall be 12 bit precision.

**[DET-18]**

Verification: Test

Conversion gain [electrons/ADU] shall be user selectable in the range from 0,3 to 2 with increment steps of at maximum 0,1.

## 4.5 Performance Requirements

**[R-STC-161-F3]**

Verification: Test

The camera shall have the capability to set scheduling parameters, as for instance the absolute starting time, on the basis of user commands with absolute precision better than 5 micro-seconds (goal 1 micro-second).

**[CAM-5]**

Verification: Test

The camera shall enable the user to set the frame period on the fly from a minimum

of 2100 μs to a maximum of at least 0,1s in increments not greater than 10μs. Frame period precision shall be 0,1% or better.

**[CAM-6]**

Verification: Test

The camera shall enable the user to set the exposure time on the fly from a minimum

of 10 µs to a maximum equal to at least the frame period decreased by 100µs. Exposure time setting increment shall be 10µs or smaller. Exposure time precision shall be 2µs or better.

**[CAM-7]**

Verification: Test

The camera shall sustain continuous streaming endurance test of at least 12 hours at 2100 µs frame period or lower and at the longest exposure time compatible with such frame period. The frame streaming shall in accordance with requirements [CAM-3] A maximum frame loss rate of 1 frame every 10000 is allowed.

**[CAM -31]**

Verification: Test

Read-out latency shall 470 µs. This latency is the amount of time from the end of the exposure till the time when the first pixel data is outputted from the camera.

**[DET-2]**

Verification: Test

Mean QE shall be equal or greater than 70% at 589 nm. The mean QE shall include the fill factor. The pixel angular response shall be better than 90% of the angular response measured at 0° for optical incident angles between -10° and +10°

**[DET-3]**

Verification: Test

Photo-Response Non-Uniformity (PRNU) at 589 nm over any window of 100x100 pixels shall be < 2% rms. Note: specification applies before any Flat Field corrections

**[DET-4]**

Verification: Test

The Detector shall meet all requirements over a programmable range of frame periods from a minimum of 2100 µs to a maximum of at least 0,1s

**[DET-5]**

Verification: Test

Mean Read-Out Noise (RON) over the image area shall be at maximum 3 electrons rms per pixel over the required frame rate range. At least the 95% of the pixels shall have RON below twice the specified mean value.

**[DET-6]**

Verification: Test

Mean dark current shall be at maximum 50 electrons/s/pixel. At least the 95% of the pixels shall have the dark current below twice the specified mean value.

**[DET-8]**

Verification: Test

Electrical crosstalk between non-neighbouring pixels (≥ 4 pixels distance): < 2%. Percentage of charge measured in a pixel in darkness compared to pixel illuminated with half “full well”.

**[DET-9]**

Verification: Test

Detector “charge diffusion” or Point Spread Function (PSF) FWHM shall be at maximum 0.5 pixels at 589 nm

**[DET-10]**

Verification: Test

When commanded to read out from standby state (not acquiring), the mean bias level shall settle to within 3 electrons of its final value within 20 s.

**[DET-11]**

Verification: Test

Bias stability with time shall be below 3 electrons over 1 hour

**[DET-12]**

Verification: Test

Output channels gains shall have a channel to channel stability better than 5% over 1 hour.

**[DET-13]**

Verification: Test

Output gain shall have an absolute stability with time better than 5% over 12 hours and better than 10% over 1 week

**[DET-16]**

Verification: Test

Maximum detectable signal capacity per pixel shall be at least 8000 electrons per pixel.

**[DET-19]**

Verification: Test

Mean output non-linearity shall be < 5% peak-to-valley over the range 10% - 90% of the ADC dynamic with conversion gain within the specified range.

**[DET-20]**

Verification: Test

The detector shall have an area of 1100x1100 of contiguous pixels centred on the detector ±10 pixels on the longest dimension of which there shall not be more than 1 bad pixel per region of 16x16 adjacent pixels anywhere on the detector. A ""bad"" pixel is defined such as having dark current or linearity or full well capacity or RON that deviate by more than 20% from the mean value of the other pixels.

## 4.6 RAMS

**[RAMS-1]**

Verification: Analysis

The camera and any Auxiliary Equipment shall have a minimum lifetime of 10 years.

For the demonstration of the lifetime requirements it shall be assumed that preventive/predictive maintenance, including environmental protection will be performed as planned.

**[RAMS-3]**

Verification: Inspection

The camera shall be delivered with a full set of technical publications and support documents (e.g., cabling diagrams) so that the camera can be installed, commissioned, operated, maintained and supported through its operating life.

Technical publications relevant to both hardware elements of the camera (e.g. cabling diagrams) and software elements of the camera (e.g. a User Manual) shall be provided. Among these documents the following ones shall be provided at minimum: installation manual, user manual, maintenance manual

**[RAMS-4]**

Verification: Analysis

All optical elements in open air shall be tested or certified to guarantee their lifetime of 10 years at minimum

**[RAMS-5]**

Verification: Inspection

If a camera is delivered with a proprietary communication Software Development Kit (SDK), the provider shall provide evidence that there is support for this communication SDK.

**[RAMS-6]**

Verification: Test

Firmware provided with, or developed for, the camera, shall be supportable.

For example, the end user shall be able to implement firmware upgrades, which are provided by the camera vendor in support of their camera product.

**[RAMS-7]**

Verification: Test

The Camera's firmware shall be upgradable without breaking the seal of the Camera head.

**[RAMS-50]**

Verification: Inspection

All camera-related software (incl. compiler suite) and firmware, which is developed for the specific use of the camera, shall be provided to the customer as source code, for the purposes of long-term archiving and obsolescence management.

**[RAMS-8]**

Verification: Analysis

FMECA analysis shall delivered with camera RAM documentation.

**[RAMS-9]**

Verification: Analysis

As output of FMECA analysis an estimation of MTBF and MTTR shall be provided.

**[RAMS-10]**

Verification: Analysis

At least an MTBF of 100000 hours (TBC) has to be guarantee.

**[RAMS-11]**

Verification: Analysis

If the loss of a function caused by any failure mode will not become apparent to the operator under normal circumstances (e.g. the failure mode is not monitored) then preventive/predictive maintenance actions shall be identified for ensuring the availability of that specific function.

**[RAMS-12]**

Verification: Analysis

All not monitored failure modes have to be prevented by suitable preventive maintenance plan

**[RAMS-13]**

Verification: Inspection

A lower limit evaluation for the number of switch on/off transitions without failures has to be provided

**[RAMS-16]**

Verification: Inspection

The maintenance manual must specify activities and related workpower and resources need to maintain the camera with the declared MTBF

**[RAMS-16b]**

Verification: Inspection

Either the maintenance manual or the user manual shall contain troubleshooting guide.

**[RAMS-17]**

Verification: Inspection

In case of failure that need maintenance by the provider the average assistance time shall be specified

**[RAMS-18]**

Verification: Inspection

Where possible, provisions shall be made that replacement of cables and connectors is possible without dismounting additional elements.

**[RAMS-19]**

Verification: Inspection

System identification that provides the capability of tracing wiring, power sources, etc. for the identification of components without use of drawings shall be maximized

**[RAMS-20]**

Verification: Inspection

The camera provider shall declare a minimum support period of at least 15 years for which the camera support is guarantee

**[RAMS-21]**

Verification: Inspection

Test and maintenance software shall be provided

**[RAMS-22]**

Verification: Test

The camera shall include user commanded Built-In Test (BIT) capability that can isolate and detect failures

**[RAMS-23]**

Verification: Inspection

If corrective maintenance operations are described in the maintenance manual, workpower and resources need to be specified.

**[RAMS-24]**

Verification: Analysis

When designing for Maintenance, the provider shall assume the following:

- The user is a skilled technician with access to but no prior knowledge of the as-built characteristics of the device;
- The user is able to run extended diagnostics to determine the scope of preventive or corrective maintenance;
- The user is unable to make any hardware modification beyond replacement of spare parts (LRUs).

**[RAMS-25b]**

Verification: Inspection

Each Camera shall provide a space on its external packaging to install a user serial number. The serial plate shall be either glued or screwed onto the camera. The space for this serial number shall be at least 40 x 15 mm

**[RAMS-26]**

Verification: Inspection

All connectors shall be marked to identify them. All mating sockets shall also be correspondingly marked

**[RAMS-27b]**

Verification: Inspection

Any precaution and/or procedure needed to properly install, removal and handle the camera shall be specified by the producer.

**[RAMS-28]**

Verification: Analysis

No wear-out functional failure mechanism, characterized by an increasing failure rate, shall occur in the lifetime of the equipment. Any components requiring preventive replacement in order to achieve this requirement shall be clearly highlighted for consideration and approval by the customer.

**[RAMS-29]**

Verification: Test

Where data from reliability libraries (e.g. Bellcore/Telcordia, NPRD-95, MIL-HDBK-217, etc.) for electrical, electro and electro-mechanical components are not available and where a failure of a specific component will be safety-critical (i.e. risk score (s) is high or medium, see AD5), an accelerated reliability testing technique, like the Highly Accelerated Life Tests (HALT), shall be applied to ensure that the quantitative reliability requirements of the Technical Specification and RAM and Safety Analyses are achieved.

The list of components for which an accelerated reliability testing technique is foreseen shall be provided for approval the customer.

The accelerated reliability testing technique to be adopted shall be agreed, too.

**[RAMS-30]**

Verification: Analysis

Where redundant components are used to achieve the availability and reliability targets, the provider shall demonstrate that Common Cause Failures have been taken into account in the RAM Analysis and the risk of their occurrence minimized.

**[RAMS-31]**

Verification: Inspection

The ESO Safety Conformity Assessment described at AD5 shall be implemented.

**[RAMS-32]**

Verification: Inspection

All hazards associated with the camera shall be analysed, assessed, and mitigated according to the hazard analysis process defined in AD5.

**[RAMS-33]**

Verification: Design

No hazardous materials or substances, as defined by Restriction of Hazardous Substances (RoHS) directives shall be used in the design and construction of a camera.

**[RAMS-34]**

Verification: Inspection

The Camera shall conform to safety requirements listed in AD1 and shall bear the CE mark based on this norm.

**[RAMS-35]**

Verification: Inspection

All cables and cable routing means shall not propagate fire in accordance with AD2 and shall be of the low-smoke zero-halogen (LSZH) type.

**[RAMS-36]**

Verification: Inspection

The Provider shall include with the delivery a Declaration of Conformity (DoC) to the safety standards AD1 and AD2.

**[RAMS-37]**

Verification: Inspection

The user and maintenance manual cannot foresee operational conditions for which the declaration of conformity cannot be applied

**[RAMS-38]**

Verification: Test

The camera shall be protected from any fault condition that may result in damage, in particular, due to the following out-of-range conditions:

• temperature, pressure, and humidity due to internal or external factors

• voltage or current of supplies

**[RAMS-39]**

Verification: Inspection

The camera user manual shall contain a list of alarm conditions, including

• their severity

• type of alarm generated

• corrective actions necessary.

**[RAMS-40]**

Verification: Test

The camera shall not be damaged by a sudden loss of power.

**[RAMS-41]**

Verification: Design

The camera shall be intrinsically safe and shall not rely on external to prevent damage to the camera (e.g., due to over-temperature, etc).

**[RAMS-42]**

Verification: Analysis

The camera and all of its subsystems shall conform to the applicable EU Directives and their Essential Health and Safety Requirements.

**[RAMS-43]**

Verification: Analysis

Within the process of hazard analysis and risk assessment any combination of two of the following additional types of failures (including two identical ones) shall be analysed:

a) Hardware failure,

b) Software failure,

c) Operator error.

None of these events shall lead to an unacceptable or undesirable hazard as defined in AD5. This includes the mechanical limitation of stroke of all moving parts.

**[RAMS-45]**

Verification:

The result of hazard analysis and mitigation shall contain hazard of acceptable level of risk, as defined in AD1, only

**[RAMS-46]**

Verification: Analysis

All risk mitigation that requires SIL level or PL level shall be listed and accepted by the customer

**[RAMS-47]**

Verification: Inspection

As general rule, the camera shall implement its own Instrument Interlock and Safety (ILS) System that controls safety functions and interlocks, if needed. If not possible, it has to be declared and approved by the customer.

**[RAMS-48]**

Verification: Inspection

A specific quality plan compliant to the quality plan of the customer shall be produced and implemented for all activities relates to camera production.

**[RAMS-49]**

Verification: Inspection

If the supplier is not ISO9001 certified, under request of the customer PA manager, it shall provide evidence that the production and service provision proceeds under controlled conditions, thus assuring that manufacturing and procurement processes are under adequate control and monitoring.