

Design and Development Status of the Dutch EAGLE-1 Optical Ground Station

F. Silvestri^a, D. de Bruijn^a, B. Dekker^a, N. Doelman^a, C. Duque^a, R. Fernandez Delicado^a, T. Hooftman^a, L. Kaffa^a, W. Klop^{a,*}, C.W. Korevaar^a, G. Kramer^a, S. van Kuijk^a, M. Lemmen^a, S. van der Linden^a, H. de Man^a, T. Moens^a, D.-N. Nguyen^a, B. Perlingeiro^a, M. Putra^a, M. Spruijt^a, G. van der Veen^{a,**}, R. Vink^a, R. Voorhoeve^a, F. de Wit^a, L. van der Laan^b, J. Peters^b, M. Neefs^b, R. Serphos^b, A. Krzic^b, S. Firpi^c, M. Minozzi^c, M. Melozzi^c, M. Bartolomei^c, L. Bonardi^c, G. Carozzi^c, N. Fior^c, A. Carlesso^c, G. Riccardi^d, N. Brechenmacher^d, G. Varewijck^e

^aTNO High Tech Industry, Delft, The Netherlands; ^bAirbus Netherlands, Leiden, The Netherlands;
^cOfficina Stellare, Sarcedo, Italy; ^dSES, Betzdorf, Luxembourg; ^eESA, Noordwijk, The Netherlands
* Currently with FSO Instruments, Delft, The Netherlands,
** Currently with ITEC Equipment, Nijmegen, The Netherlands

ABSTRACT

EAGLE-1 is intended to demonstrate the first European end-to-end space-based Quantum Key Distribution (QKD) system, enabling QKD service delivery via optical space and ground segment terminals. The programme is led by SES Techcom and the European Space Agency (ESA), with support from the European Commission and a consortium comprising more than 20 industrial and institutional partners. Within the EAGLE-1 User Segment, a consortium led by TNO, in collaboration with Airbus Netherlands and Officina Stellare, and supported by FSO Instruments, Demcon, and Celestia STS, is developing a Demonstrator Optical Ground Station (OGS). The OGS is intended to support satellite service operations, provide representative operational data for the future European Quantum Communications Infrastructure (EuroQCI), and functions as a trusted-node access point for end users of quantum encryption keys. Installation is planned in Noordwijk, the Netherlands, with delivery foreseen in early 2028. This paper presents the OGS architecture, principal functionalities, and current development status.

Keywords: Quantum Key Distribution, Optical Ground Station, Laser Communication

1. INTRODUCTION

EAGLE-1 is a European In-Orbit Validation mission aimed at demonstrating end-to-end satellite-based Quantum Key Distribution (QKD) and establishing the technological foundations for future sovereign quantum communication services in Europe. The programme is led by SES Techcom and the European Space Agency (ESA), with support from the European Commission and a consortium of industrial and institutional partners across multiple European Member States. The mission combines a dedicated low-Earth orbit satellite carrying a quantum communication payload with a network of optical ground segment assets, creating a representative operational environment for future secure quantum communication services [1].

The primary objective of EAGLE-1 is to validate the technologies, operational concepts, and system architectures required to provide QKD services through space-based infrastructure. By overcoming the distance limitations inherent to terrestrial fibre-based quantum communication networks, satellite-based QKD offers a practical path towards secure key distribution on continental and global scales. Beyond demonstrating individual technologies, EAGLE-1 seeks to validate the complete service chain, including key generation, transmission, operational procedures, and integration with user communication networks.

Within this framework, the Dutch Optical Ground Station (OGS) forms a key element of the user segment. The Dutch OGS is being developed by a consortium led by TNO, in collaboration with Airbus Netherlands and Officina Stellare, and supported by FSO Instruments, Demcon, and Celestia STS. Each partner contributes specialised expertise in optical systems, adaptive optics, telescope technology, wavefront sensing, optical communications, control systems, and system

integration. The resulting ground station is intended not only as a technology demonstrator, but also as a representative precursor of future operational optical ground stations capable of supporting quantum communication services. A distinguishing characteristic of the Dutch EAGLE-1 OGS is its combination of adaptive optics, high-performance optical tracking, quantum-signal reception, and classical optical communications within an integrated architecture. The system is designed to provide representative performance data under operational conditions, enabling the assessment of both technical performance and operational concepts. The experience gained during development, integration, commissioning, and operation is expected to contribute significantly to future European optical communication infrastructures.

EAGLE-1 occupies a strategic position within the broader European Quantum Communication Infrastructure (EuroQCI) initiative. EuroQCI aims to establish a secure and sovereign quantum communication network spanning the European Union, combining terrestrial fibre networks with space-based segments to achieve continent-wide connectivity. Within this roadmap, EAGLE-1 serves as one of the first operational-scale demonstrators of space-based QKD in Europe, providing essential validation of technologies, interfaces, operational concepts, and service models required for future deployment. The mission therefore represents an important intermediate step between technology development activities and the establishment of a fully operational European quantum communication infrastructure.

The paper structure is as follows: Section 2 provides an overview of the design of the OGS, dedicating each subsection to the description of the relevant subsystem; Section 3 provides an overview of the realization planning and the approach used for the integration and verification of the system.

2. OPTICAL GROUND STATION: DESIGN

Architecture

The EAGLE-1 User Segment is a network of Ground Terminals (GT) at different locations which serve as the interface to provide the users with the corresponding cryptographic product. It consists of two elements:

- Ground Terminal(s)
- User Network

The Ground Terminal (GT) contains

- QKD Ground System
- Optical Ground Station(s) (OGSs)

As already mentioned, this paper is exclusively about the Dutch Optical Ground Station, which is to be deployed in Noordwijk.

The EAGLE-1 OGS communicates with the space segment via three optical channels all operating in C-band. The classical Rx and Tx are decoded and encoded respectively in the Classical Optical Modem (see separate section on the modem design), and the QKD ground system is providing the user Tx data and receiving the user Rx data. The third channel which is the QKD Rx channel is routed by the OGS via a single mode fibre interface to the QKD ground system, which detects the qubits and carries out all the steps needed on ground to generate and securely store the quantum keys. The EAGLE-1 optical design is monostatic, meaning that all three channels use a shared telescope and (in part) share the optical bench. This ensures a good co-alignment between the channels.

The EAGLE-1 satellite orbit is a sun-synchronous LEO orbit. The telescope and the dome are designed such that they can track the spacecraft; the control is done autonomously by the Operational Control System (OpCS) software.

The OGS is designed to establish a link at a minimum elevation of 25 degrees. The establishment of communication between the spacecraft and the OGS follows the SDA protocol. The EAGLE-1 mission operation centre shares a prediction of the spacecraft orbital positions during the pass in Consolidated Prediction Format (CPF) to the EAGLE-1 OGS Operator (for further details see section OGS Operations and Control System), which is used for the OGS pointing acquisition and tracking of the satellite during a link.

A key part of the OGS is the Optical Ground Terminal (OGT) which can be seen as the opto-mechanical systems receiving and transmitting the laser beams and thus implements the conversion from a free space optical beam to a fibre based optical signal and vice-versa. The core elements of the OGT (Telescope, Adaptive Optics Optical Bench, Optical Bench Control Systems) are described in dedicated sections in the following of the text.

An artist impression of the exterior of the EAGLE-1 OGS with the location of the main components is displayed in Figure 2-1.

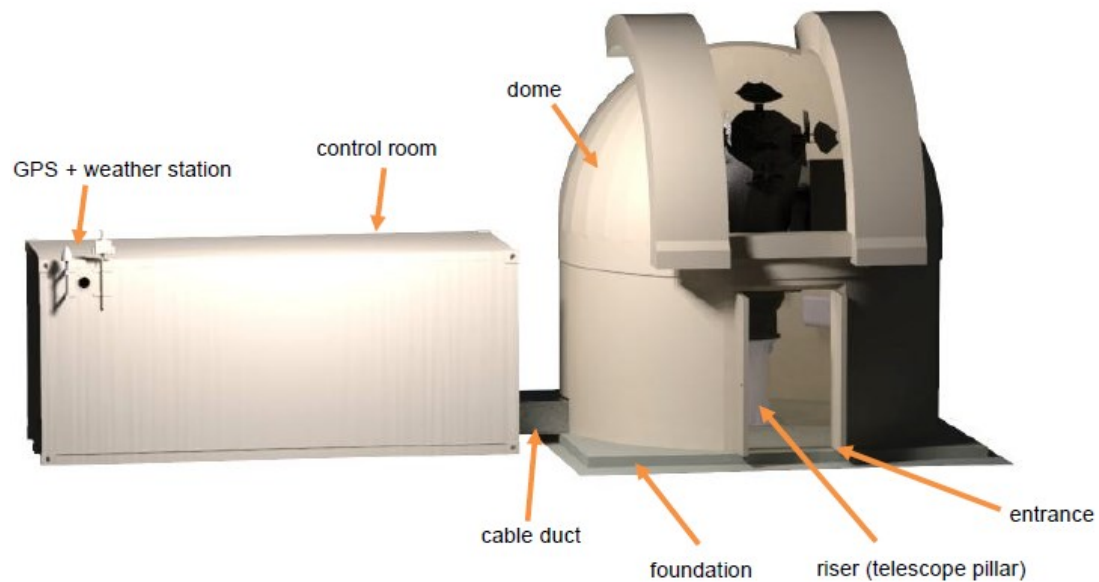


Figure 2-1 Exterior EAGLE-1 OGS artist impression

The OGS is designed such that it can be placed on a wide variety of sites, however the OGS to be realized has a dedicated foundation design, since this is site specific by nature and needs to be based on local ground soundings. For the site in Noordwijk a site-specific design has been made, which includes next to the foundation also the general setup of the site, provisions for cable routing, fence, CCTV, streetlights and landscape aspects. An artist impression of the OGS site is reported in Figure 2-2.



Figure 2-2 Site EAGLE-1 OGS artist impression

OGS Operations and Control System

The EAGLE-1 OGS is aimed at receiving and sending optical data from/to the EAGLE-1 satellite. The OGS concept of operations aims at achieving the following objectives:

- Receive and decode user data from the satellite terminal (optical to digital conversion)
- Receive quantum signal and transfer it to QKD Ground System via an optical fibre
- Encode and transmit user data to the satellite terminal (digital to optical conversion)
- Support secure communication
- Provide remote operation
- Guarantee high availability

The diagram in Figure 2-3 shows the operational context of the OGS which is performing a bi-directional link with the EAGLE-1 spacecraft. The OGS is commanded by the OGS Operator and in return the OGS is providing telemetry data on the status of the subsystems as well as logging link data. The OGS has no visibility on the actual data shared between the Payload Operation Center (POC) and the spacecraft; only the QKD ground system has access to that data. Note that the architecture is single-user oriented. Outside the link windows, the OGS Operator performs OGS contingency procedures, such as telescope pointing model and other subsystem calibrations, which are carried out in the dedicated maintenance mode.

In case of problems with the OGS equipment the OGS support center has access to the OGS for troubleshooting purposes, the OGS support center is also in charge of cyber security aspects.

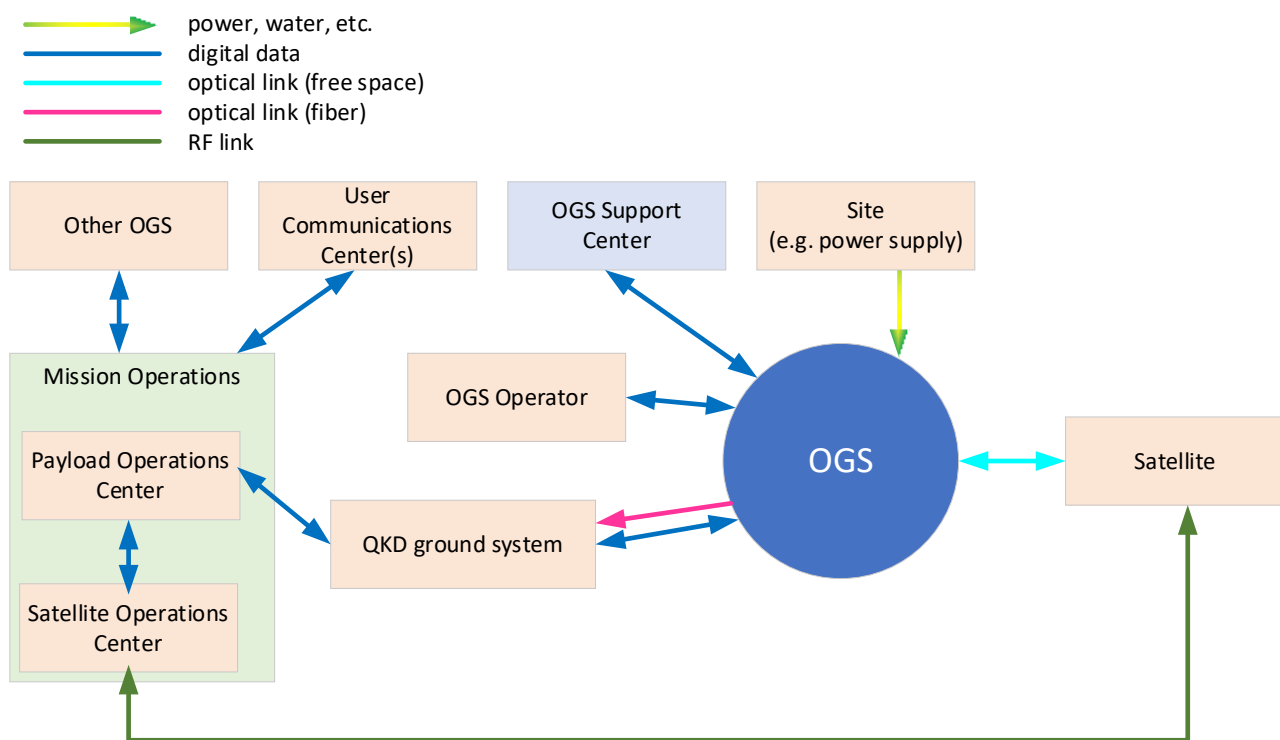


Figure 2-3 EAGLE-1 OGS context diagram

To establish communication between the OGS and the satellite terminal, the following steps are foreseen

- The OGS Operator requests a link
- POC defines the feasibility on the desired day(s) / time-slot(s) and shares a mission plan and corresponding CPF files with the OGS
- OGS Operator assesses the OGS status and confirms or cancels the planned link (based on local operability).

If confirmed:

- POC/SOC prepares the space segment
- OGS proceeds with operations (starting state)

- The OGS autonomously prepares the optical link (preparation state)
- The OGS autonomously acquires the link (acquisition state)
- The OGS establishes communication with the spacecraft (tracking state)

During the link:

- The POC and the OGS Operator can see the monitoring data via the M&C interface and via the OGS remote desktop
- The QKD Ground System provides the Tx data to the Classical Optical Modem
- The QKD Ground System receives the Rx data via the Classical Optical Modem and QKD Rx channel via the optical fibre from the Adaptive Optics Optical Bench
- The OGS terminates the link and puts the OGS in parking mode (safe state)
- After the link The POC can access the OGS monitoring data via a machine-to-machine interface.

The OGS is controlled by software state machines at two levels: OGS operations level and internal software level. At the highest level, the OGS Operation Control System (OpCS) is a state machine that governs the operations of the ground station. The set of possible states of this state machine are the OGS modes: this is the operational state of the ground station from the viewpoint of the end user and is closely related to the PAT sequence. This state machine is implemented in the Monitoring & Control software component. From the OGS Operator perspective the OpCS is the single interface to control the whole OGS including all its major subsystems (Telescope, Adaptive Optics Optical Bench, Classical Optical Modem).

At the lower software internal level, the OpCS uses a microservice architecture composed of independent software modules. A Configuration Manager software component is dedicated to consistently start-up the microservices of the subsystems present in the OGS. This component is a state machine in its own which gives rise to the OpCS software states.

Telescope

The EAGLE-1 telescope is an ultra-high stability, F/10 Ritchey-Chrétien (RC) telescope, featuring a flat mirror (M3) located between the two curved mirrors M1 and M2 to divert focused radiation to two different Nasmyth foci. The primary mirror (M1) has a diameter of 800 mm, while the central obstruction diameter is 245 mm, ensuring a linear central obscuration < 31% tailored for QKD applications. The optical layout of the telescope is reported in Figure 2-4, while a complete overview of the telescope system is reported in Figure 2-5.

The operating rotation ranges are the following:

- 540° on azimuth, -270°/+270° from zero clock;
- 90° on elevation, from horizon to zenith.

The environmental conditions both storage and operative are (at sea level altitude):

- 5-95% of relative humidity
- -20°C ... +50°C.

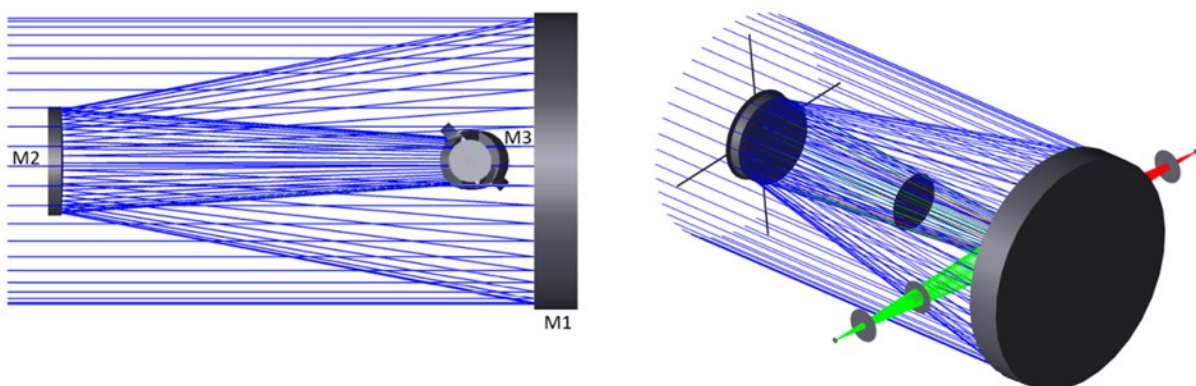


Figure 2-4 Telescope optical layout

According to the requirements, the telescope shall have a long focal length and a low obscuration over a ± 1.5 mrad field of view (FoV). Also, it must operate both in the visible and in the SWIR wavebands. Consequently, an RC design is adopted since it provides a diffraction-limited FoV without the need for additional refractive components. The expected wavefront-error (WFE) is well below 85 nm on the entire FoV and under all operative conditions.

In addition, a third flat folding mirror is conceived in the design to achieve the Nasmyth configuration with two accessible Nasmyth ports. One Nasmyth port is the operational one and it is connected to the Adaptive Optics Optical Bench, while the second one is free to be used during telescope calibration (e.g. plate solving) or in general for different applications.

An enhanced aluminium coating was developed and optimized to increase reflectivity in the SWIR bandwidth while, at the same time, minimizing the difference between S and P polarization at 45° incidence in the whole 1500-1600 nm band. Final performance ensures an average transmittance of the whole telescope, greater than 40% in the 450-800 nm and greater than 95% in the whole 1500-1600 nm band for QKD and classical laser communications.

Due to the stringent requirements of the EAGLE-1 focal plane stability, the entire M1 cell has been redesigned compared to a standard telescope configuration. The M1 mirror is supported by an 18-point whiffletree system. The 18 points of contact are positioned to minimize the strain energy induced by gravity. Moreover, the mirror is supported from the inner side by a M1 box with axial flexures. An external mask made in aluminium and painted with Aeroglaze Z306 is present to define the outer optical diameter (800 mm).

To satisfy the stringent EAGLE-1 central-obscuration requirement, a new M3 assembly has been developed. This assembly is designed to rotate and tilt the flat mirror M3 between multiple foci stations. A direct-drive actuation allows the system to rotate the mirror with high accuracy and repeatability, without the need to implement an anti-backlash system. A brake is implemented to lock the position of the M3 assembly once the desired position is reached. The brake is used also as a safety measure to lock the rotation of the M3 assembly in case of power loss. A four-point contact bearing is used to provide high stability and stiffness throughout the full range of motion. Furthermore, the M3 mirror is mounted on a mechanism and a linear actuator, preloaded with springs to tackle backlash, is used to provide the tilting correction. The signal of the microswitches is used to trigger the safety brake. The M3 assembly is provided with two degrees of freedom (DOF), namely clock and tilt.

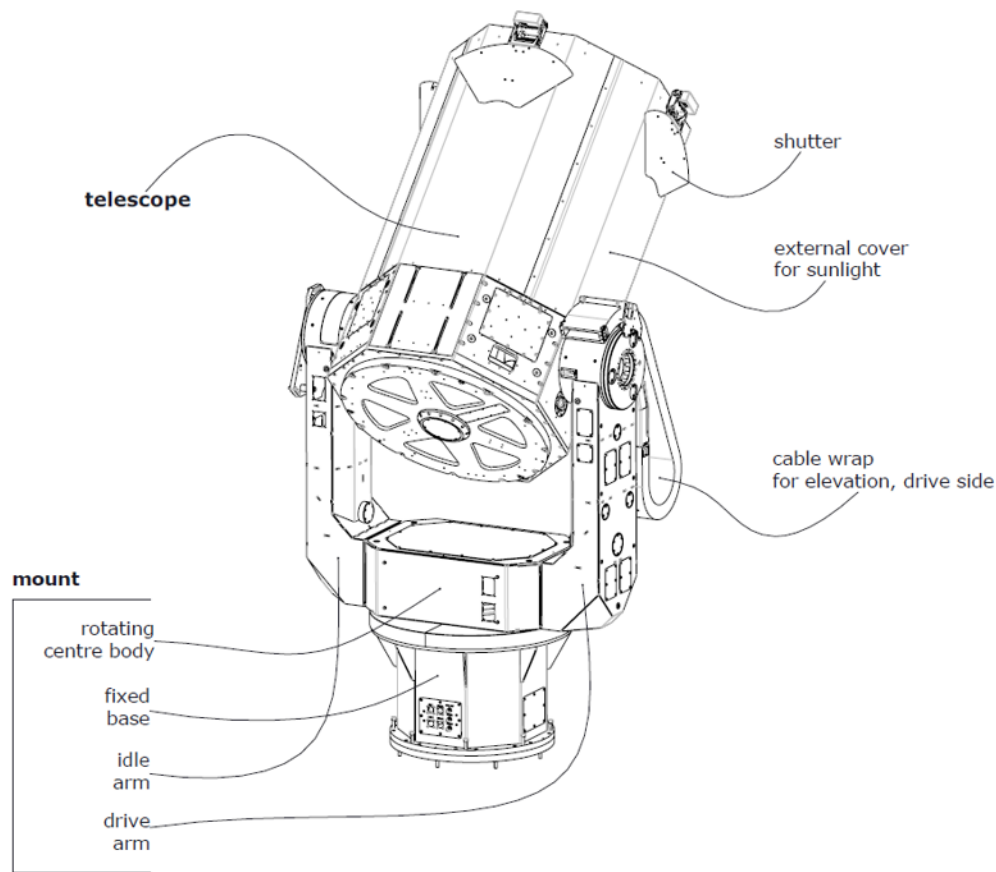


Figure 2-5 Overall view of the telescope subsystem

Adaptive Optics Optical Bench

The Adaptive Optics Optical Bench (AOOB) is the opto-mechatronic subsystem of the EAGLE-1 Optical Ground Terminal responsible for conditioning, routing, stabilizing, and coupling the optical beams associated with the free-space optical link. As displayed in Figure 2-6, its main purpose is to receive optical radiation from the telescope interface, separate the relevant spectral and functional channels, enable the acquisition and tracking strategy, correct the downlink wavefront, and couple the communication and quantum channels into their respective single-mode fibre interfaces. In parallel, the AOOB injects the transmitted optical beams into the telescope path, establishing the required angular relationship between the received and transmitted beams, including the required point-ahead angle, enabling the pointing scanning of the transmitted beam, to be employed as beacon by the satellite terminal during the link acquisition phase. Additionally, the AOOB provides a specific path for internal diagnostics and calibration of the Adaptive Optics (AO) system and a visible spectrum path, with a Star Field Camera, which provides to the Telescope control system the required star-imaging to calculate the pointing-model for the telescope movement correction.

A central design driver for the AOOB is the preservation of fibre-coupling performance under realistic operational disturbances. The received optical field is affected by atmospheric turbulence, scintillation, residual telescope pointing errors, mechanical vibration, thermal drift, and non-common-path alignment errors. The AOOB design addresses these disturbances through a combination of passive optical quality, active tip/tilt stabilization, adaptive wavefront correction, calibration provisions, and controlled opto-mechanical interfaces

The AOOB provides two receiver fibre interfaces: one dedicated to the reception of a QKD signal, directed towards the Quantum Receiver [2], the other one allocated to Classical Optical Communication, which is received by the Classical Optical Modem. Both channels share the same free-space to fiber interface and they are chromatically split with fibre-based components.

To enable a stable link with the satellite, the AOOB implements two complementary feedback controlled loops. The first one consists of an acquisition and tracking sensor (ATS) and of a fine-steering mirror (FSM). The ATS, based on an focal plane InGaAs array (Xenics-Exosens), provides the angular error signal with respect to the equivalent angular fibre position, and the FSM (FSO) provides an accurate and fast angular correction. The correction function for this loop is calculated within the OBCS, which is also dedicated to the conditioning of the data stream, with a closed-loop bandwidth* of 500 Hz during the tracking and communication phase.

To be able to correct for the beam deformation induced by the atmospheric turbulence, the AOOB implements a second feedback controlled loop based on a high-order AO system (up to 155 orthogonal modes over the full aperture), consisting of a deformable mirror (DM, Alpao) and a Wavefront Sensor (WFS). Demcon has developed specifically for this project a Shack-Hartmann WFS based on the same InGaAs array as for the ATS (Xenics-Exosens), with a specified control update rate of 10 kHz. The OBCS is responsible for the conditioning of the signals from and to the DM/WFS, for the derivation of the actual wavefront from the InGaAs array detected irradiance and for the calculation of required DM actuation, based on an orthogonal modal single-input-single-output control strategy.

The transmitted path is implemented by injecting multiple transmit beams through dedicated fibre interfaces into the AOOB and relaying them towards the telescope interface. The fibres emerge from multiple High Power Erbium-Doped-Fiber-Amplifiers (Woodrow Scientific), which amplifies the signals transmitted by the Classical Optical Modem (COM). The use of multiple transmitted beams supports transmitter diversity on the uplink. At functional level, this approach increases robustness against atmospheric-channel variability by distributing the transmitted optical power over multiple beams rather than relying on a single uplink beam [3]. The AOOB provides the free-space optical routing and beam conditioning needed to place these transmitted beams at the appropriate pupil locations and with the required angular relation to the receive path. The point-ahead functionality, implemented with an active tip-tilt mirror (Optics-In-Motion), is part of this transmit architecture and compensates for the apparent angular displacement between the instantaneous receive direction and the required transmit direction. This point-ahead functionality is coupled with a derotator mechanism which rotates the position of the transmitting beams over the pupil, counteracting the pupil-rotation induced by the Nasmyth configuration of the telescope, preventing any optical interference of the telescope secondary struts on the transmitted beams propagation.

The optical layout of the AOOB is characterized by the use of custom lenses and mirrors (Optimax Systems, Laseroptik) to ensure a low residual static wavefront. Dichroic beamsplitters (Chroma Technology) allow for separation of the beams and for control of cross-talk between the different wavelength channels. Straylight control is further improved by use of baffling and field stops. To achieve a high level of system efficiency for the QKD reception, a distinctive beam-shaper has been fully in-house developed by TNO. The beam shaper, based on transmissive optics, transforms the typical donut-shape irradiance profile of the telescope pupil into a quasi-Gaussian profile, with minimum wavefront error. The transformation towards a quasi-Gaussian irradiance profile allows to overcome the theoretical fibre coupling efficiency limit, due to the mismatch of mode distribution between receiving fibre and telescope pupil.

The complete AOOB is thermally enclosed and it has integrated a liquid-cooling circuit, to stabilize the operational temperature of the components within a few degrees of variation. The complete system is contained within a volume of less than 50 liters and with a mass below 80 kg. The AOOB is mechanically mounted on the EAGLE-1 Telescope fork, to allow for a direct optical coupling, by means of the Nasmyth-type port of the telescope. A render of the final optomechanical design is reported in Figure 2-7.

* This bandwidth characterizes the dynamic response of closed-loop system including sensors, controllers, actuators, and any inherent delay in communication, and it is therefore a different value from the sensor update rate mentioned in section “Optical Bench Control System”.

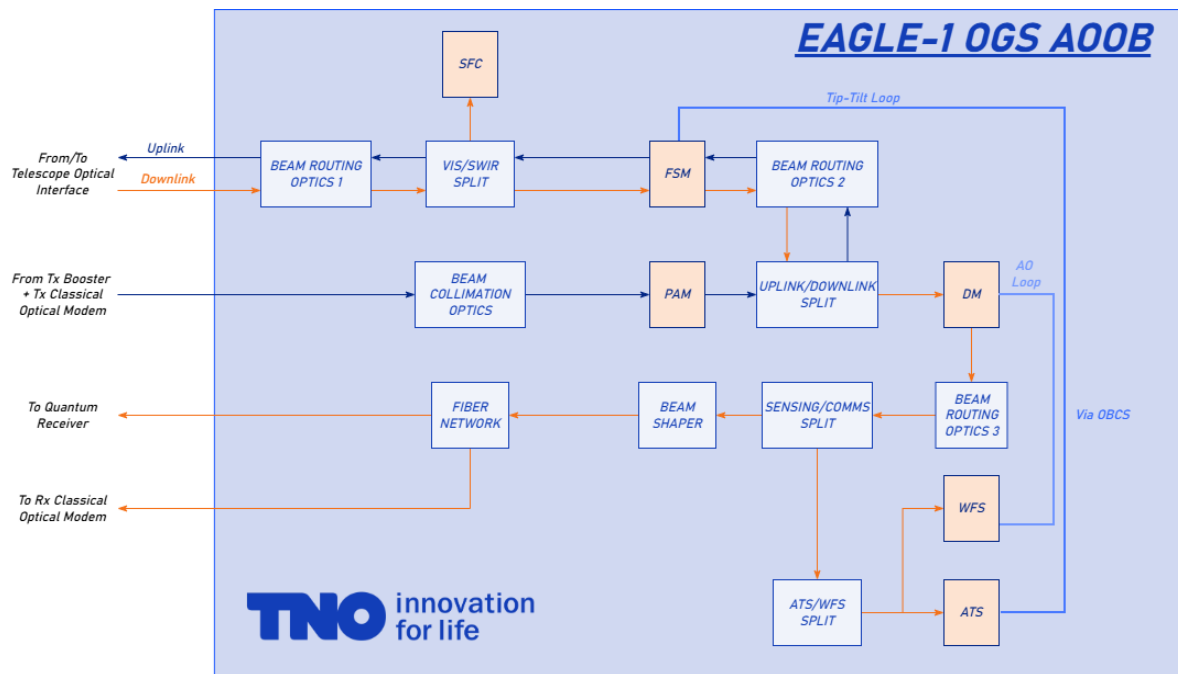


Figure 2-6 Functional optical layout of the AOOB

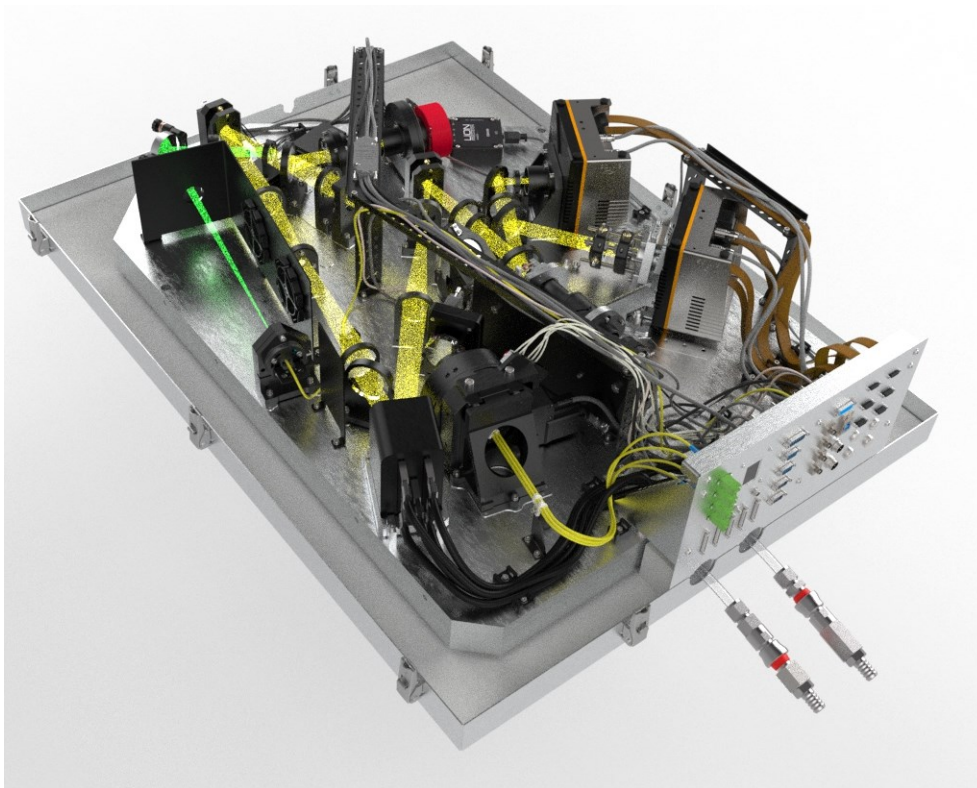


Figure 2-7 3D Render of the AOOB

Optical Bench Control System

The OGT Optical Bench Control System (OBCS) for EAGLE-1 implements the monitoring and control of the EAGLE-1 Adaptive Optics Optical Bench or AOOB. The OBCS will perform the following main functions:

- Control the AOOB, including both the real-time tasks (e.g., adaptive optics control loop) and the non-real-time tasks (e.g. calibration procedures and environmental monitoring)
- Monitor and log key performance metrics of the AOOB.
- Acquire high speed Rx intensity data from the modem
- Manage the required acquisition and tracking states of the AOOB part of the EAGLE-1 PAT sequence
- Control and monitor the Tx boosters during link operation

The main design driver for the OBCS is to provide the control functions and performances required to achieve optimal fibre-coupling under the local atmospheric disturbances. As described in the AOOB section, two closed loops are implemented. The ATS – FSM Tip Tilt loop for first order corrections and the WFS – DM Adaptive Optics loop to correct for higher order wave front errors. Both loops will operate at a sensor update rate of 10 kHz in tracking and communication mode. In particular, the adaptive optics control loop is computationally demanding. The WFS sensor data generates up to 800 wave front slopes, and the DM has 308 actuator elements. The AO controller is required to process the WFS data, perform the required transformations and control the DM elements with a maximum latency of 50 μ s. The AO controller will implement a state space controller supporting up to 155 modes with a 4th order controller per mode. To implement these functions with minimal latency, the OBCS design uses FPGA implementation of the time critical functions. After analysis of the specified control loops and the available resources of existing FPGA platforms, it has been decided to allocate dedicated FPGA systems to the AO loop and Tip Tilt loop. This allocation is feasible since the control loops are independent and they do not need to communicate to each other for the control implementation. The EAGLE-1 OBCS therefore consists of three main components: the Non Real-Time Controller (NRTC) and two Real Time Controllers (RTC-TT and RTC-AO). The RTCs implement the hard real-time control functions, the NRTC performs the non real-time functions such as the operator interfaces and control low-speed or asynchronous components in the AOOB. The RTC-TT is based on the control system developed in earlier laser satellite communication projects [5]. The RTC-AO is developed specifically for the EAGLE-1 project and it uses an FPGA of the latest generation with sufficient resources to implement the AO control algorithms.

The figure below shows the RTC-TT and its operator interface software running on the NRTC.

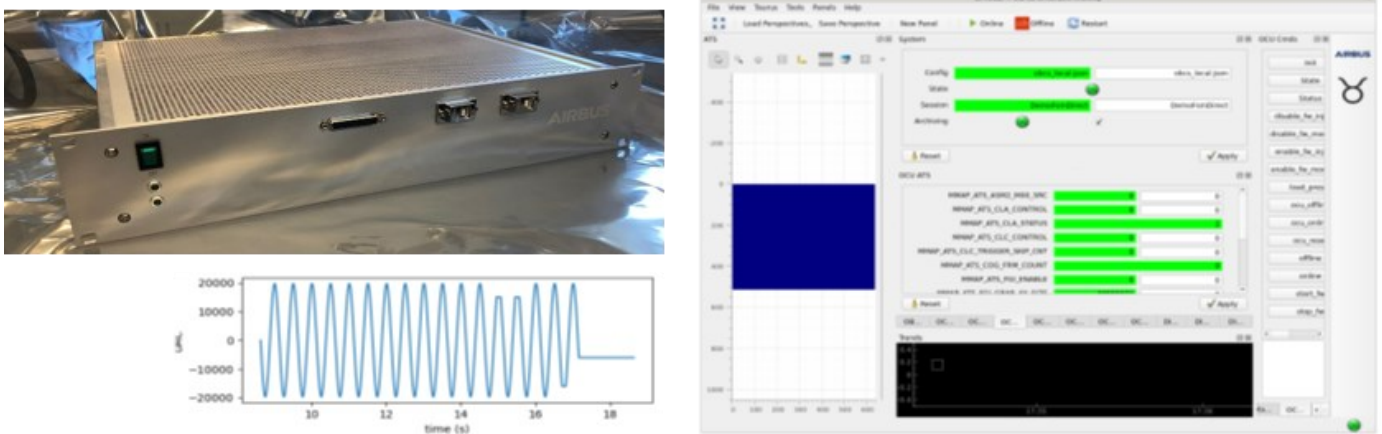


Figure 2-8 The RTC-TT and its monitoring and control software

In addition to the challenging operational performance, the OBCS will support high speed characterization and parameter logging. These functions will be used extensively during AOOB integration and OGT performance evaluation. The

OBCS is designed to be highly configurable with configuration files and runtime changeable parameters, to support a flexible integration of the firmware/software control system with the hardware of the AOOB. The extensive scripting functions will allow users to optimize the use of the OBCS both during integration and in the operational phase.

Classical Optical Modem

The Classical Optical Modem (COM) provides the bidirectional classical communication link between the EAGLE-1 Optical Ground Station and the satellite terminal. It is developed specifically for this project by Celestia-STS. In addition to supporting telemetry and data transfer, the classical channel enables critical QKD functions, including the exchange of protocol information required for key reconciliation and system synchronization. The modem therefore provides the interface between conventional terrestrial networks and the free-space optical communication link. The COM is compliant with the Space Development Agency Optical Intersatellite Link (OISL) Standard v2.1.2 and is interoperable with the TESAT ConLCT modem onboard the EAGLE-1 spacecraft [4]. Framing, coding, synchronization, error correction, and Automatic Repeat reQuest (ARQ) handling are performed in accordance with this standard. The bidirectional link uses On-Off Keying Non-Return-to-Zero (OOK-NRZ) intensity modulation with direct detection, at a fixed symbol rate of 312.5 MBaud, with dedicated wavelengths for the transmit and receive channel.

The modem design is driven by the need to maintain reliable communication over a highly dynamic atmospheric channel while ensuring interoperability with the space-terminal communication system. Unlike terrestrial optical networks, free-space optical links are affected by strong power fluctuations due to varying link conditions, turbulence-induced scintillation, beam wander and residual pointing errors. At the same time, strict compliance with standardized communication protocols and compatibility with the counterpart space modem are essential for end-to-end system operation. These requirements are key drivers for the modem architecture and verification approach.

For the uplink, user data is formatted and encoded, after which the digital data stream is modulated onto the optical carrier. The uplink supports transmitter diversity by modulating and amplifying four transmit signals, which are launched as spatially separated beams. This approach improves robustness against atmospheric fading. To ensure mutually incoherent beams and avoid destructive interference, each transmit beam is assigned a distinct wavelength within the receiver-bandwidth of the space terminal [3]. To further avoid inter-symbol interference at the satellite receiver, the modem compensates path-length differences among the transmitters.

For the downlink, the received optical signal is amplified, detected, synchronized, decoded, and delivered as a digital data stream to the QKD Ground System.

In addition to data communications, the modem provides monitoring and diagnostic capabilities. Performance metrics such as received optical power, communication status, synchronization quality, and error statistics are continuously recorded and made available to the system operator. These functions support both real-time operations and post-link performance assessment of the optical communication link.



Figure 2-9 Picture of the Classical Optical Modem. Optical Modem unit containing the downlink modem opto-electronics, and the Optical Front End beacon unit containing the opto-electronics needed for generation, modulation and control of the uplink communication stream.

3. OPTICAL GROUND STATION: INTEGRATION AND OPERATION PLAN

In summer 2026 the project has started its realization and integration phase. The different partners are working on converging paths, working separately on the verification of requirements and performance at component level, moving towards integration and inter-operability verification in the next months. Given the strong functional interdependency between the AOOB and the OBCS, the approach used for integrating them together is to work already with incremental versions of the OBCS since the beginning of the AOOB integration. This shortens the time for debugging and troubleshooting, and allows the initial opto-mechanical alignment to be supported by the automation of active components. This approach also results in a coupled AOOB-OBCS system which is verified-as-being-integrated, providing full high-level performance and functional verification, without waiting for the complete realization of the two separated subsystems.

The OGS construction is planned to start in Q3-2026. Completion of the Dutch EAGLE-1 OGS is planned for early 2028. This schedule is compatible with the phased commissioning strategy of the EAGLE-1 system, in which the satellite first undergoes in-orbit testing and commissioning, performed with a second OGS [6], before end-to-end service validation is performed with the operational ground segment described in this paper. An end-to-end testing phase will follow the delivery of the OGS. This testing phase is aimed at the characterization of the actual link performance, and it serves as commissioning for the final operational phase, which is planned to be executed over a period of 3 years.

4. CONCLUSION

This paper has presented the design and current development status of the Dutch EAGLE-1 Optical Ground Station. The station combines an 800 mm Ritchey–Chrétien telescope, a monostatic optical architecture, adaptive wavefront correction, high-bandwidth fine tracking, transmitter diversity, bidirectional classical optical communication, quantum-signal reception, and autonomous operations within a single integrated facility. Together, these capabilities address the principal challenges of establishing reliable optical links with a low-Earth-orbit spacecraft through a dynamic atmospheric channel. Construction of the OGS is planned to commence in 2026, with completion and acceptance foreseen in early 2028, followed by end-to-end commissioning and a three-year operational phase. At the conference, the latest status of the integration activities will be presented.

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