SAGA QUANTUM KEY DISTRIBUTION OPTICAL GROUND STATION SPECIFICATIONS

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APPROVAL

Title	SAGA QUANTUM KEY DISTRIBUTION OPTICAL GROUND STATION SPECIFICATIONS		
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CHANGE LOG

Reason for change	Issue Nr	Revision Number	Date
REQ-RX-010, REQ-RX-90 removed	1	1	09/11/2023
REQ-SYS-21, REQ-ENV-31 added	1	1	09/11/2023
Comments from Engineering board included	1	2	02/29/2024
Further comments included	1	2	11/03/2024
Removed grey shadings	1	2	11/10/2024
Replaced S1G with SAGA	1	2	22/10/2024

CHANGE RECORD

Issue Number 1	Revision Number 1		
Reason for change	Date	Pages	Paragraph(s)
IRD version with ESA UNCLASSIFIED - Limited Distribution content.	11/06/2023		
1.2 Background added, figure 1 changed	11/27/2023		
Comments from Engineering board included	02/29/2024	All	all

DISTRIBUTION

Name/Organisational Unit

Table of Contents

1. INTRODUCTION

1.1. Scope of the Document

This document describes the requirements for optical ground stations that intend to connect to the future SAGA system. ESA is currently developing the SAGA system and the following requirements have been consolidated in the context of the SAGA I-SRR and therefore ESA cannot exclude minor modifications to these requirements in the future. This Requirements Document does not cover operations and logistics requirements.

Member states need to start development of Optical ground stations, which shall be able to receive key material from ESA missions like SAGA or Eagle-1. This document is particularly targeting compatibility with the SAGA satellite.

It shall be noted that EuroQCI is intended for classified service in the future and final security requirements will be applicable. However, security requirements are out of the scope of this document which is intended for a wide dissemination. Security Requirements applicable to an OGS connecting to SAGA will be separately provided at a later stage.

1.2. Background

The European Quantum Communication Infrastructure (EuroQCI) consists of a Terrestrial Segment, composed of the National QCIs, and a Space Segment. SAGA is an in-orbit demonstrator of the EuroQCI space segment. SAGA system will initially have 4 optical ground stations for its own verification and validation purposes. Member states shall develop their own optical ground stations to connect to the SAGA system for accessing key material provided by the space segment. An ESA external sharable Interface control document (ICD) is required to ensure system compatibility of optical ground stations developed by the member states. A high-level Interface requirement document (IRD) has been defined in the SAGA Phase B1, further break down is part upcoming Phases. The IRD is a classified document and only accessible by ESA and contracted Industries.

This document has been created, to share information with the member states wishing to connect to SAGA, which are not security sensitive, but are solid ground for optical ground station developments. The document is based on experience from previous ARTES and GSTP activities and includes generic requirements for optical ground stations designed for polarisation based prepare & measure QKD protocols. The document has been reviewed and released by the ESA Security Office (ESO) with the marking ESA UNCLASSIFIED – Limited Distribution. The CSC Director released the document further for public use.

This document is a forecast on the final SAGA Optical ground station specs and can be shared with the EC and their member states. The member states shall be enabled to develop user segments which will be compatible with the EuroQCI space segment. Member states can only provide optical ground stations with an interface to a user end point providing a secure environment for classified components, developed by ESA.

A classified area (part of a UEP) and it's interfaces to the OGS (IF-2/IF-3) should comply with national security requirements for sites potentially hosting classified equipment like: Optical receivers for the quantum channel and the classical communication channel including modem and KMS.

1.3. Applicable and Reference Documents

1.3.1. Applicable Documents (ADs)

The following documents, listed in order of precedence, contain requirements applicable to the activity.

In the event of conflict between applicable documents and detailed requirements expressed in this document, the requirements of this Statement of Work take precedence.

Ref.	Title	Reference and Issue
AD 1	EuroQCI_ConOps_v2.0	EC: https://digital-strategy.ec.europa.eu/en/miscellaneous/euroqci-conops-concept-operations
AD 2	EuroQCI_MRD	TBC

1.3.2. Reference Documents (RDs)

The following documents can be consulted by the Contractor as they contain relevant information:

Ref.	Title	Reference and Issue
RD1	SDA OCT Standard v3.1.0	https://www.sda.mil/wp-content/uploads/2023/06/SDA_OCT_Standard-3.1.0_Signed_Web_Version.pdf
RD2	Optical Communications Physical Layer	CCSDS 141.0-B-1 https://public.ccsds.org/Pubs/141x0b1.pdf
RD3	OPTICAL COMMUNICATIONS CODING AND SYNCHRONIZATION	CCSDS 142.0-B-1 https://public.ccsds.org/Pubs/142x0b1.pdf
RD4	Safety of laser products - Part 1: Equipment classification and requirements (IEC 60825-1:2014)	https://www.beuth.de/de/norm/din-en-60825-1/344085844

1.4. Acronyms and Abbreviations (alphabetical order)

EuroQCI	European Quantum Communication Infrastructure
OGS	Optical ground station
QKD	Quantum key gerneration
SAT	Satellite
AO	Adaptive Optics
CLA	Classified environment
TX	Transmitter
RX	Receiver
FOV	Field of view
SEP	Sun earth probe
SMF	Single mode fiver
KMS	Key management system
LEO	Low earth orbit
PAA	Point ahead angle

SNSPD	Superconducting nanowire single photon detector
FC/APC	Fiber connector / angled physical contact
QBER	Quantum bit error rate

2. REQUIREMENTS

2.1. Functional requirements

Requirement ID	Parameter	Value and Units	Comments
Functional Requirements			
REQ-FUN-010	The OGS shall be a functional, complete stand-alone optical ground station including all corresponding sub-systems.		
REQ-FUN-020	The OGS shall support optical communication to and from LEO satellites (between 400km and 800km height).		
REQ-FUN-030	The OGS shall be able to perform sidereal tracking of stars and the recording of images from all cameras. Note: For calibration.		
REQ-FUN-040	The OGS shall have a time series database and visualisation system for measurement of all relevant system and subsystem parameters.		
REQ-FUN-050	The OGS shall be compatible with the SDA OCT Standard v3.1.0 [RD.01] Particularly the pointing acquisition and tracking strategy.		
REQ-FUN-060	The OGS shall be compatible with the CCSDS 141 & 142 standards [RD.02], [RD.03]		
REQ-FUN-070	The OGS shall be able to track sun-illuminated satellites with as low brightness as 5 magV. Note: For calibration.		

2.2. OGS general requirements

<table>
<tr><td>REQ-GEN-010</td><td>The OGS shall include the following major subsystems:
a) station computer (local scheduler, measurement and control of all subsystems, local data storage),
b) telescope and mount
c) environment protection,
d) full RX adaptive optics bench,
e) tip/tilt TX adaptive optics benches with fiber amplifier,
f) laser safety,
g) local weather forecast,
h) satellite emulator (for self-testing prior to satellite passes).</td></tr>
<tr><td>REQ-GEN-020</td><td>The OGS shall include the following major interfaces:<table><tr><td>I1.</td><td>Space-to-OGS optical interface, (air-interface)</td></tr><tr><td>I2.</td><td>Classical fiber interface from optical bench to secure zone
(SMF28, FC/APC connector)</td></tr><tr><td>I3.</td><td>Quantum interface from optical bench to secure zone
(SMF28 / FC/APC connector; or free-space)</td></tr><tr><td>I4.</td><td>OGS network interface,
(10Gbps, SMF28, LC/PC connector)</td></tr><tr><td>I5.</td><td>Power interface
32A, 3 phases, 380V AC</td></tr></table>Note: The network interface can be used for the remote control of non-classified OGS functions.</td></tr>
<tr><td>REQ-GEN-030</td><td>The OGS shall operate eye safe according to EN 60825-1 [RD.04] for all C-band wavelengths.</td></tr>
<tr><td>REQ-GEN-040</td><td>The OGS shall comply with national health- and safety-regulations.</td></tr>
<tr><td>REQ-GEN-050</td><td>Public data exchange between OGS and SAT shall be performed via an optical channel.</td></tr>
</table>

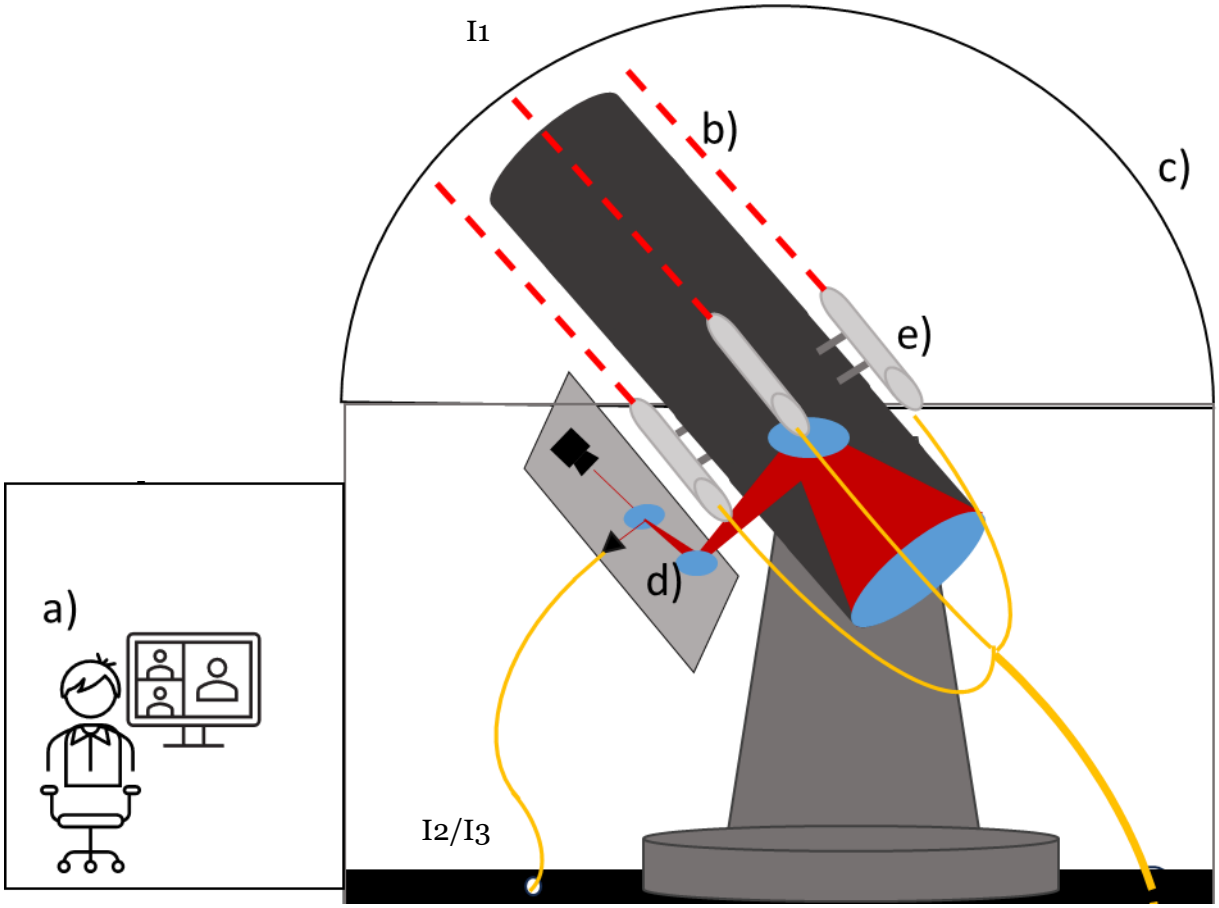

Figure 1: Not binding, Illustration of optical ground station: a) operator room, b) telescope, c) dome, d) receiver bench e) optical transmitters.I1 space-ground interface, I2/I3 receiver interfaces OGS – UEP.

2.3. Pointing acquisition & tracking requirements

PAT requirements			
REQ-PAT-010	Star sensitivity for telescope pointing model determination	Better than 13 apparent magnitude	Assume 1s integration time.
REQ-PAT-020	OGS sensitivity	< -30 dBm/m²	The OGS shall achieve full performance with the irradiance specified.

2.4. Receiver requirements

Receiver requirements			
REQ-RX-010	Telescope aperture	>=70 cm	
REQ-RX-020	Telescope linear central obscuration	< 35%	
REQ-RX-030	Receiver channels	1547 - 1595 nm, 780 – 860 nm (optional)	For QKD and classical receiver channels
REQ-RX-040	Static optical losses receiver path	< 5 dB	Losses from telescope free-space interface (IF-1) to receiver modules (IF-2/IF-3) shall be kept as small as possible.
REQ-RX-050	Dynamic adaptive optics SMF coupling loss	< 5 dB down to 20° elevation	For QKD and classical channel. In urban environment, sea level altitude, under clear-sky and at average operative turbulence and wind conditions.
REQ-RX-060	AO fried parameter range	>5.5 cm	@1560 nm and 60° elevation
REQ-RX-061	AO Greenwood frequency range	</= 600 Hz	temporal atmospheric fluctuations to be considered for AO correction
REQ-RX-070	Polarisation extinction ratio	> 20dB between orthogonal Polarizations in any possible basis.	s-p phase retardation and depolarization shall be minimized to maintain a system QBER of below 1%.
REQ-RX-080	Receiver channel optical interface	The receiver channel optical output interface shall either be a single mode fibre or an optional collimated free-space output with a radius of 2,5mm ($1/e^2$) at IF-2/3.	The fibre will add flexibility to guide the optical signal towards the classified area.

REQ-OPT-090	Self-test fibre interface	FC/APC connector SMF-28 compatible.	The purpose of this interface is to be able to inject optical signals simulating the satellite terminal into the optical bench for testing, e.g. optical modem or QKD signals. Polarization maintaining fibres would disturb the quantum states and cannot be used.
REQ-RX-100	Coarse Acquisition sensor FOV	>+-1 deg	To cover thermomechanical deformation, roof-top movement and incidental large orbital uncertainties during daylight.
REQ-RX-110	Fine Acquisition sensor FOV	>+- 4 mrad	To cover ephemeris data uncertainty.

2.5. Transmitter requirements

Uplink transmitter requirements			
REQ-OPT-040	Classical transmitter channels	1530 - 1537 nm	
REQ-TX-010	TX channels	4	Scintillation shall be reduced be multi aperture or multi frequency allocation.
REQ-TX-020	TX power	> 5 W (per channel)	At air interface (IF-1). Might require large TX apertures (>100 mm).
REQ-TX-030	RX TX co-alignment precision	+- 5 urad	On Sky.
REQ-TX-040	TX PAA angle range	+- 250 urad	A computer controlled PAA mirror with spiralling capabilities has to be included.
REQ-TX-050	Angular alignment stability	+- 2 urad	Over the whole operational temperature range.
REQ-TX-060	TX divergence	50 urad ($1/e^2$ radius)	Can potentially be relaxed / traded with power.
REQ-TX-070	TX adaptive optics order	Shall be capable of closed loop closed loop tracking, e.g. via Tip/Tilt system.	Tip/Tilt shall be pre-compensated for the uplink, using the downlink signal received from the spacecraft as feedback.
REQ-TX-080	TX path transmission	< 1 dB	From collimator output of TX fibre to telescope input.

2.6. Mechanical requirements

Mechanical Requirements			
REQ-MEC-010	Power connector	IP65 rated single connector	
REQ-MEC-020	Slew rate	>10 deg/s	
REQ-MEC-030	Tracking speed	>1 deg/s	While maintaining pointing accuracy.
REQ-MEC-040	Spiral scanning speed	< 20 sec.	Scanning of the full ground to space pointing uncertainty cone shall be possible. (Either via telescope or transmitter)
REQ-MEC-050	Blind tracking precision	< 10 urad (1σ)	At max tracking speed.
REQ-MEC-060	Blind tracking trueness	< 20 urad (1σ)	At max tracking speed. Dominating contributor to ground uncertainty cone
REQ-MEC-070	Blind pointing precision	< 2 urad (3σ)	Static pointing at stars.
REQ-MEC-080	Blind pointing trueness	< 10 urad (3σ)	Static pointing at stars
REQ-MEC-090	Elevation range	0 – 90° >10° >15° >20°	mechanical acquisition and tracking classical communication QKD material reception
REQ-MEC-100	Azimuth range	-270 - 270°	
REQ-MEC-110	SEP angle	> 30°	Sun-Earth probe angle shall be large to protect single photon detectors (no daylight transmission foreseen)

2.7. Environmental requirements

Environmental Requirements			
REQ-ENV-010	Operational wind speed	0 – 60 km/h	Peak in a 1 min interval.
REQ-ENV-020	Operational temperature	-20 – 45°C	Shall provide service availability of 99,9% at service location.
REQ-ENV-050	Operational humidity	90% rH	Might require encapsulation.
REQ-ENV-060	Cold-start time	<1 h	Time from supplying power to thermally stable operations.
REQ-ENV-070	Operation time	The system shall be operable 24h, at day and night-time.	
REQ-ENV-080	Lifetime: - Ground	 > 10 years	
REQ-ENV-090	Survival wind speed	0 – 200 km/h	
REQ-ENV-010	Survival temperature	-40 – 55°C	
REQ-ENV-110	Survival humidity	100% rH	Rain.