Lunar Communication and Navigation services – 1st generation in 2024, followed by a constellation by end 2020s

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ABSTRACT

Introduction: November last year, SSTL Lunar presented Lunar Pathfinder to the MVA, the first data-relay spacecraft to offer commercial communication services around the Moon. In December 2021, the programme is already 10 months into development, and the services defined. On the user side, QinetiQ has also started development of their user terminal, to make it available to service users. Looking ahead, ESA Moonlight is putting a framework around the future generation of lunar communication and navigation services.

Lunar Pathfinder: From 2024 onwards, lunar missions of all types will be able to access the service and dramatically enhance the value of their mission by lifting the multiple constraints of transferring data back to Earth today.

With a store and forward capability, a proximity link, two simultaneous channels in S-band and UHF, Lunar Pathfinder data-relay spacecraft is designed to lift all the constraints linked to the use of Direct To Earth (DTE), allowing longer upload durations at higher data-rates with each of the lunar assets, and bulk-sending data, at high speed, back to Earth Ground Station, ready for distribution to the end users.

In addition to its main mission, Lunar Pathfinder will also carry a hosted payload, an ESA GNSS receiver, with the objective of running a GNSS weak signal detection experiment from lunar orbit, a significant step towards navigation service provision for lunar assets.

QinetiQ User Terminal: QinetiQ builds on its long heritage of delivering Mars communication (e.g. Melacom, ExoMars) to provide the flexible Lunar Link Transponder for the Lunar Pathfinder Satellite and to evolve the User Terminal solution for customers of the SSTL lunar mission services.

Lunar comms and nav constellation (ESA Moonlight initiative): Building upon the Lunar Pathfinder experience and the commercialization of its services, an SSTL-led consortium, including established telecom operators as well as space and ground segment integrators, is already working on the next generation infrastructure. With a space segment based on a constellation of data-relay orbiters and strong interoperability requirements with other infrastructure elements such as Gateway, the overall system will integrate into the backbone infrastructure that will enable sustainable lunar exploration and utilization.

Conclusion: Vital part of the lunar infrastructure, necessity to a sustainable future for lunar exploration, instrumental link between lunar assets and Earth, offering low-cost and high performance to all assets, the Lunar comms and nav orbiters is only a few years away, contact us now?

PAPER

Acronyms:

CLPS	= Commercial Lunar Payload Services
CLMSS	= Commercial Lunar Missions Support Services
DTE	= Direct to Earth
ELFO	= Elliptical Lunar Frozen Orbit
FWD	= Forward
GES	= Goonhilly Earth Station
GNSS	= Global Navigation Satellite System
ISRU	= In-Situ Resource Utilization
ISS	= International Space Station
PNT	= Positioning, Navigation and Timing
RTN	= Return
SSTL	= Surrey Satellite Technology Ltd
Telco	= Telecommunication service provider
TM/TC	= Telemetry and telecommand

I. Introduction

We, as a community of scientists, researchers, explorers, space industrial organisations and institutions are facing a new challenge today: humanity is returning to the Moon, making the *Vision of the Moon Village: present*, the topic of our MVA discussion today, a reality. If this Moon Village is to be sustainable, it will rely on lunar service infrastructure, in support to scientific exploration, a whole lunar economy is now emerging, with activities throughout the value chain, involving space and non-space sector actors, from both commercial and institutional sectors.

2021 marks a historical turning point in the history of space activity, with the emergence of a space for space economy, where products and services that are being produced in space are also consumed, utilised in space rather than back on Earth, and with the rise of the private sector onto activities largely dominated by institutions until now. In particular, looking at the transport sector, SpaceX are now offering to transport private astronauts to the ISS on a commercial basis, and Blue Origin recently announced their project of setting up a fully commercial space station, as a "mixed-use business park", providing infrastructure that companies need to open new markets in space.

Today, the same is happening with lunar support services such as communication and navigation. The principle is identical, industry taking the initiative to provide capabilities that were traditionally the remit of institutions, for institutions at first, with an eye on creating a new, fully commercial market: off-planet telecommunication (telco). The objective is to build, operate and sustain an essential service, a commodity to be enjoyed by all without a second thought: the ability to position oneself and to communicate back home. Who on Earth would think about living without?

This paper explains the path that SSTL has followed so far, with our partner ESA, to be in a position to offer communication data-relay services as early as 2024. The paper starts with a high level description of what lunar services via relay satellites are, showing the user need and the value of the new infrastructure. This paper then shows details of the market and traffic model of the demand, which forms the basis of the commercial endeavour. The subsequent paragraph describes the initial service offer made available by SSTL's pioneer satellite Lunar Pathfinder and some elements of the mission. Before concluding, the paper looks at what comes next after Lunar Pathfinder, and presents the ESA Moonlight initiative, and the way SSTL Lunar is responding to the challenge with a very strong industrial consortium, and equally strong ambitions to see a constellation operating lunar communication and navigation services around the Moon.

II. Lunar communication and navigation services via data-relay satellites

Once on the surface or in orbit around the Moon, lunar assets need to communicate back and forth with Earth. It may be to exchange commands and house-keeping data (TM/TC) or returning research findings, video, analysis etc. Without data-relay satellites, this can be done either via direct to Earth (DTE) capabilities, which means that the lunar asset has direct view to a ground station located on Earth, and enough directivity and power to send the data through. It can also be done via local surface relay, for instance via the lander acting as a data hub, and transferring the data back to Earth via DTE. But what happens if the asset is on the far-side of the Moon, if there is no line of sight? Or if geography gets in the way? What happens if the lander doesn't survive the lunar night but the dependent rover does? What happens if the scientific mission can afford the science, but not the expensive transponder necessary to send the data back to the Earth ground station?

Similarly, assets need to be able to precisely log their position on or around the Moon, as well as the time. Today, positioning is done through ranging, which requires Earth ground station dish time for long periods, frequently, and often doesn't offer the necessary precision to secure critical manoeuvres or the necessary autonomy for precise teleoperations.

a) Why is there a need for such an infrastructure?

The idea behind Commercial Lunar Mission Support Services (CLMSS), partnership between SSTL and ESA, and ESA Moonlight [4] Lunar Communication and Navigation Services, is to build a proximity lunar infrastructure that brings an answer to the above questions and limitations.

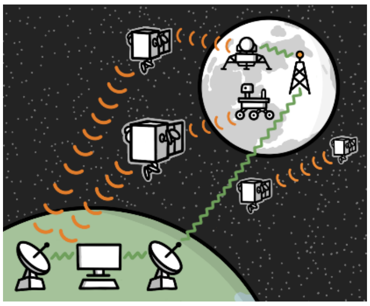


Fig. 1 - Artistic view of lunar relay infrastructure

Communication services via data-relay satellite offer a service, available to any asset in any lunar location, to transfer data between two assets. In the long term, it may be between the asset and the team on Earth, or between 2 assets within the lunar vicinity.

Navigation services offer PNT services, again to any type of asset and in any lunar location, removing the need for ranging or computing location on-board.

Depending on the nature and the location of the lunar mission, the benefits of having a local relay infrastructure for Lunar communication and navigation services are varied.

b) Quick analysis of market demand

SSTL Lunar has been analysing the anticipated market for communications for many years. This analysis involves identifying known missions, characterizing the communication needs of these mission based upon their type and synthesizing the data through statistical analysis to account for uncertainties in the market.

The Moon is fast becoming the new economic frontier of the global space economy with many missions already planned from both public and private organizations. China currently has circa 8 operational spacecraft around the Moon, last year landings were attempted by both Israel & India, and three American missions are due to land next year (2022). There is also an opportunity for the generation of real economic value on the Moon should ISRU enable the refining of Hydrogen and Oxygen from the water trapped in the regolith.

NASA wishes to return to the Moon in a sustainable way and has initiated the Commercial Lunar Payload Service (CLPS) program with the aim of flying two missions to the moon each year. This shows a strong will from NASA to have a significant commercial involvement in the core missions as well as the support services. Thus far, NASA has awarded contracts for 6 flights and is on track for further task orders, landing lunar assets on polar and far-side locations on the Moon. ESA, as well as other international space agencies, are also declaring their lunar ambitions, with numerous opportunities for landers, rovers, static payloads as well as orbital assets.

This strong activity and its promise on demand for both data relay and navigation services is reinforced again by the position of NASA and ESA, who encourage industrial partners to supply their dish time using commercial dish networks, and to only rely on the institutional networks such as DSN or ESTRACK if there is no other available solution.

Since 2020, both ESA and NASA have expressed interest in lunar communication and navigation infrastructure, through their respective initiatives ESA Moonlight, covered in section V of this paper and NASA LunaNet [3]. This clearly indicates the trend for institutions to create opportunities for the private sector to collaborate with them, and develop a service that can be offered both commercially and institutionally.

Without going into the details of the market analysis and modelling tool allowing to predict the demand for both communication and navigation services, a quick look at some data enables us to derive the main market trends:

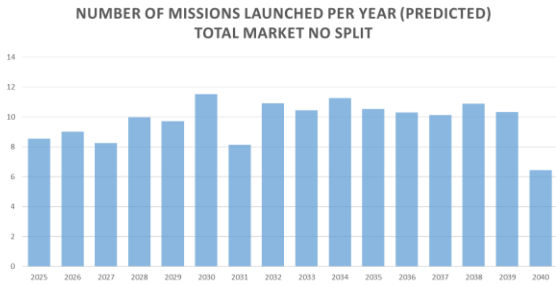


Fig. 2 - Mean number of new missions launched per year

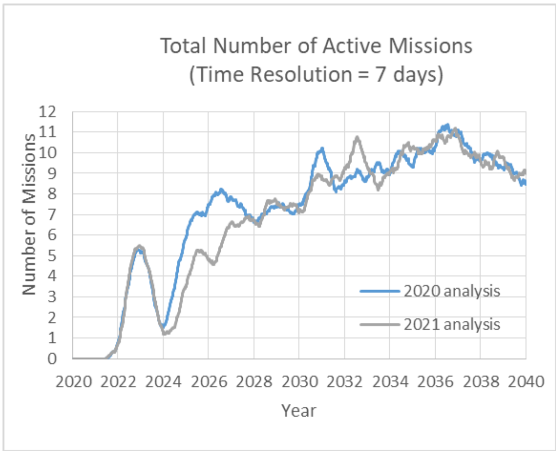


Fig. 3 - Total number of active missions (time resolution = 7 days)

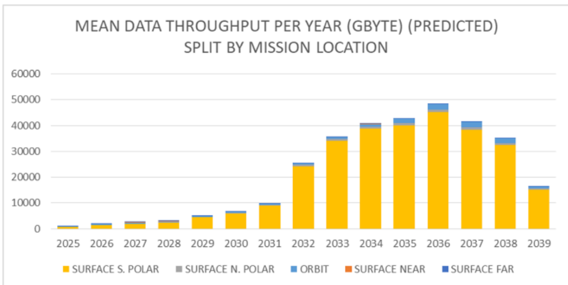


Fig. 4 - Data throughput per lunar destination

Fig. 2 shows the mean number of new missions being launched per year. The overall trend is a slow increase of the number of missions, year on year, with a relatively stable distribution. Looking at the data per type of missions, this clearly indicates a predominance of the number of CubeSats as type of mission, consistently from 2023 onwards. The flow of CLPS landers is also fairly constant, following the rhythm of the NASA CLPS program. The same can be said for the NASA Artemis missions. ISRU facilities make an appearance towards the end of 2020s.

It is particularly interesting to compare this relative constant flux of missions with the dramatic increase of number of simultaneously active missions over a week, shown on Fig. 3, as well as the data volume shown on Fig. 4. A few things worth outlining:

- From early 2020s to 2030s, peaks and troughs due to the "cargo" delivery effect. At least twice a year from 2023, several missions are to be carried on-board CLPS cargo missions or Artemis missions, creating a peak of demand for a short duration and nothing once those missions are finished.
- The second trend shows the start of sustainable presence around the Moon, which is likely to be dictated by ISRU discovery and the ability to sustain permanent presence on the Moon.
- On both figures, the 2018-20 analysis is shown in comparison with the updated 2021 analysis. The good correlation of the graphs going further into the future shows a confirmation in the intent of the programs planning a sustainable return to the Moon. It is also worth noticing that many of the earlier programs have been delayed in their development and re-estimated their planned launch date 1 year or more later. Of course, any delay on transportation missions, will multiply through the hosted payloads.
- From 2030s onwards, more durable, capable missions are likely to appear on and around the moon. With technology enabling them to survive the lunar night, they will create a more continuous demand in both communication and navigation services.

The market analysis shows that most early missions are likely to be located either on near-side surface or orbital locations, with a rapid trend towards polar locations over time. However, Fig. 6 shows that the vast majority of demand for data transfer is likely to be from polar locations. This comes from institutional missions, often more capable and more data-rich, which tend to focus on the polar location at medium term.

III. First commercialization of Lunar communication services with Lunar Pathfinder

Following the successful review of the market analysis and associated business case, ESA and SSTL signed, in summer 2020, a commercial partnership agreement for the implementation of the first commercially available lunar communication services.

Based on a service contract between ESA and SSTL, officially signed in the UK on 15th September 2021, the idea is for SSTL to develop and build a service offering for lunar communication, including a data-relay spacecraft called Lunar Pathfinder. ESA is the anchor customer for the service, providing some revenue assurance to allow industry to take the risk on the initial investment. Through bi-lateral barter, ESA will also allow for NASA to be one of the two first users of the service. In addition to the service provision already reserved for ESA and NASA, communication services will be offered to any other mission on a commercial basis.

This first implementation phase is not only a demonstration of the necessary technology for data-relay services but first and foremost an opportunity to show-case the market concept and stimulate demand.

With one data-relay orbiter, the initial services will be focused on the provision of communication services only, and will not be able to offer operational navigation services. However, other hosted payloads will allow Lunar Pathfinder to be a live test-bed for navigation experiment, as described in further detail below.

a) SSTL Lunar and initial CLMSS service offering

SSTL-Lunar is a new brand of SSTL, dedicated to the marketing and provision of Lunar support services.

With start of operational services in 2024, potential customers have already contacted SSTL-Lunar to enquire about Lunar communication services, and are in discussion about taking advantage of the early service using Lunar Pathfinder.

Fig. 5 - 4 step approach to communication services

The initial service offering is composed of 4 steps:

- Initial discussions (pre-contractual agreement) for SSTL Lunar and the potential user of the service to assess specific mission needs, initial performance and best suited service options.
- Pre-launch services, with the objective to ensure and validate compatibility of the user communication terminal with Lunar Pathfinder, and validate the functioning of the system, through a program of on-ground testing.
- In-orbit testing to validate functionalities and performance of the service prior to

starting operational communication services.

- Operational communication services, developed in the next paragraph.

The initial service offering, available at the start of the Lunar Pathfinder operations, is composed of two levels of services:

- Autonomous service: an agreed volume of data is to be relayed between ground station and user asset within an agreed period of time – the optimization of where and when the contact is established being left to an automated algorithm.
- Scheduled service: the customer is able to schedule the time of the contact with their asset (within operational window), enabling a more precise planning of the customer mission.

Starting with a limited number of services, SSTL Lunar is already looking into growing the available options for Lunar users, and design of the services, the Lunar Pathfinder mission, as well as all elements of the infrastructure is done with both scalability, interoperability and flexibility in mind.

b) Lunar Pathfinder mission and spacecraft

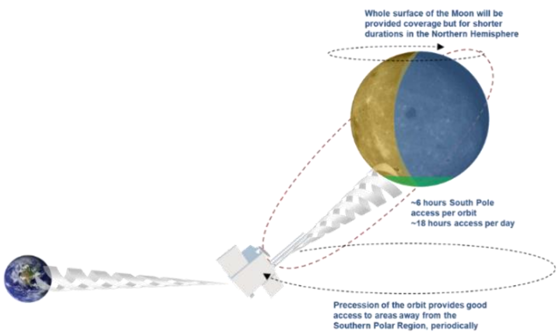


Fig. 6 - Lunar Pathfinder orbital information

Lunar Pathfinder will operate in an Elliptical Lunar Frozen Orbit (ELFO), for an operational lifetime of over 8 years.

This orbit favours a long duration coverage of the lunar southern hemisphere, understood to be more attractive for early lunar missions. It covers the far side of the Moon and benefits from long access times to Earth to relay back customers' data.

The launch and transfer to operational orbit will be provided by NASA via NASA CLPS service. After release in lunar orbit and spacecraft commissioning is complete, the service will be validated and nominal operations starts:

Provision of data relay services over S-Band and UHF to Lunar assets

- Relay to the Earth is over X-Band
- Hosted payload operations

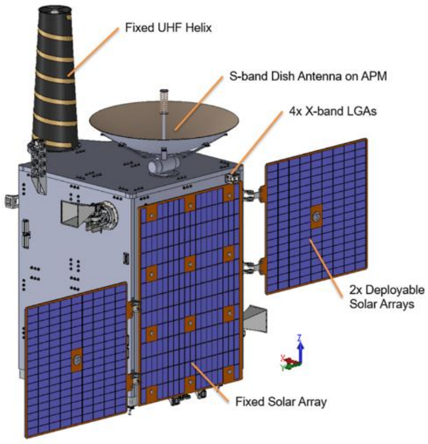


Fig. 7 - Lunar Pathfinder spacecraft

The Lunar Pathfinder spacecraft has a wet mass of approximately 330kg and is designed for a life duration of 8.5 years (accounting for communication service operations and commissioning). It accommodates a fixed solar array and 2 deployable solar arrays.

The Moon link is supported through a UHF fixed helix antenna, an S-Band dish antenna on Antenna Pointing Mechanism (APM), which feed a proximity Moon link transponder.

The Earth link used four X-Band LGAs, linked to the Earth link transponder.

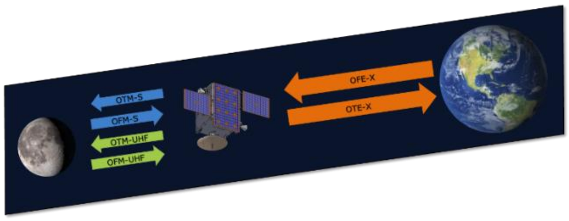


Fig. 8 - Communication links

The Lunar Pathfinder relay spacecraft is equipped with a Moon link payload, using Proximity-1 protocol, and capable of operating 2 full duplex channels simultaneously. Achievable data-rates depend both on relative position of the user asset vs. the Lunar Pathfinder spacecraft and on the performance parameters of the user terminals.

Indicative rates are as follows:

- Orbiter to Moon (FWD) S-Band/UHF 124 kbps (Rover)
- Moon to Orbiter (RTN) S-Band/UHF 248 kbps (EIRP 13)
- Moon to Orbiter (RTN) S-Band 1986 kbps (EIRP 21.5)

The Earth link is realised in X-Band, with forward data-rate (Earth to Orbiter) up to 30 kbps, and return data-rate (Orbiter to Earth) up to 5,000 kbps.

The Proximity-1 protocol is designed to work with multiple assets in the same coverage area, and with a variety of assets of various performances. All links will be controlled by the data-relay spacecraft, meaning that each transceiver will only operate on 1 RF channel at a time and multiple assets will be using this 1 channel.

To establish a link, the spacecraft hails an asset by addressing it by its Spacecraft Identification (SCID). All assets will listen to this hail but only the asset with the right SCID will respond. Communication link will then be established.

The use of Proximity-1, as initial choice for Lunar Pathfinder, allows to address a large spread of customer assets with various RF performances:

- Wide range of data rates (0.5-2048kbps)
- Links with assets of different performance RF systems and/or at different ranges to be supported on the same link
- Data rate to be dynamically adjusted over a link session as the signal strength changes to maximise data throughput
- The time when assets receive their allocation can be selected to provide better average data rate

The communication service works on a "store & forward" architecture, allowing flexibility regarding the relative position of the lunar assets, the data-relay spacecraft, and the Earth ground station. Data is stored in the payload until links are available:

- End to end link doesn't need to be available simultaneously for data to be sent between the user's Mission Operations Centre (MOC) and lunar asset data is stored at each node in the network until it can be sent on
- Commands and software patches ultimately destined for the asset can be sent to the data-relay spacecraft even when the asset is not in view of the Earth
- Data can be stored at the ground station until the next access to the data-relay spacecraft.

This approach brings additional flexibility and benefits to the users:

- Duration and schedule for ground station accesses can be varied based on amount of data to transfer and user operational requirements, thus reducing operational costs
- Provides operational flexibility to users as they can work normal hours rather than having to be available for end-to-end links

For potential customers, a "mission builder" tool is now available on the SSTL Lunar webpage [1], allowing potential users to get a predicted coverage and performance report based on a few high level characteristics of their mission.

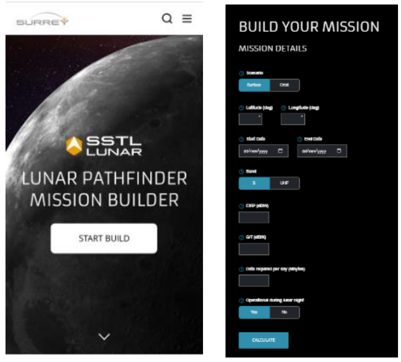


Fig. 9 - SSTL Lunar mission builder tool (screenshot from SSTL website)[1]

c) Lunar Pathfinder hosted payloads

In addition to its main communication services mission, the Lunar Pathfinder spacecraft is baselined to carry a number of hosted payloads and perform pioneering experiments.

- ESA GNSS payload – ESA is to provide an advanced satellite navigation receiver in order to perform the first ever satnav positioning fix in lunar orbit. As explained by ESA in an article published on their website [2], the experiment uses weak signal detection coming from existing Earth GNSS to validate its potential use for lunar positioning.
- NASA laser retro-reflector (LRR) – The LRR equipment is to be provided by NASA, through collaboration with ESA, and will be accommodated on the same face as the GNSS antenna. This allows for LRR-based ranging experiments in parallel to GNSS weak-signal detection experiment.
- ESA radiation monitor – this passive equipment, provided by ESA, is to be sun (or deep space) facing, and will be used for technical demonstration as part of ESA's Space Weather Systems monitoring.

d) Ground segment (baseline)

Depending on the market uptake and the service need, Lunar Pathfinder will use several ground stations, appropriately distributed around the Earth.

One of the baseline ground stations for the mission is GHY-6 32m antenna from Goonhilly Earth Station (GES), in Cornwall, UK, located at 50.05°N 5.18°W. The antenna is set to be complemented by others within the KSAT network.

Fig. 10 - Aerial view of Goonhilly Earth Station with GHY-6 32m dish

The service is currently designed to pass all payload data through a single ground station in the early stages of the mission.

The Earth ground stations network will be expanded to include ground station sites in other parts of the world in the future. This will extend the contact time to Lunar Pathfinder and enable greater data throughput. This will be dependent on service needs.

Like all elements of the CLMSS solution, the ground segment solution is designed to be scalable, inter-operable and retro-compatible as both ground segment and space segment evolve.

e) User terminals (in development)

To enable the use of the communication services from Lunar Pathfinder, lunar missions need to be equipped with a compatible user terminal, capable of communicating with the data-relay spacecraft. It is fundamental to the overall value of the service and infrastructure, as this user terminal should be lighter, cheaper, and in combination with Lunar Pathfinder, offer overall higher data-rates than what would have been required to communicate DTE.

UK-based company QinetiQ is working in collaboration with SSTL to develop a first family of compatibility user terminals. QinetiQ is the most experienced proximity link communications specialist in Europe and has played a key role in four Mars missions to date; our heritage has been built on MELACOM (nearly in its third decade of operation), Beagle 2, ExoMars (Schiaparelli) and ExoMars (Rosalind Franklin Rover and Kazachok Lander) missions.

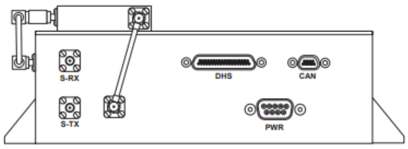
QinetiQ is currently delivering the Lunar Link Transponder for the Lunar Pathfinder satellite and is developing a compatible 'sister' technology for Users of the Lunar Pathfinder service to allow organisations that are taking assets to the moon (e.g. rovers, CubeSats, landers) to access the Lunar Pathfinder service.

QinetiQ's Lunar Link User Terminal will be a low-mass, high performance solution providing full-duplex Proximity-1 E2n link capabilities at, initially, S and/or UHF band. The product is based on the same architecture as the Lunar Link transceiver on the Lunar Pathfinder satellite to ensure high compatibility. It features a flexible, software-defined architecture which allows for exceptional performance and reconfigurability.

Its key features will include a CCSDS Proximity-1 protocol (full duplex, simplex receive and simplex transmit modes), CAN bus for C&M, RS-422 interface for data transfer, a reconfigurable FPGA for software updates and reconfigurations on-mission, and a flexible channel selection compatible with SSTL's Lunar Link service.

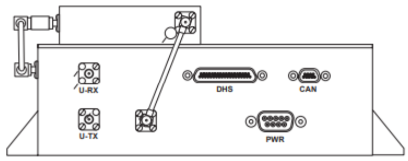
S-Band

Dimensions include top mounted filter but exclude connectors and mounting feet.



Dimensions	140 x 110 x 50 mm
Mass	1.00 kg

UHF Band

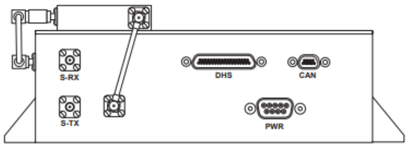


Dimensions	140 x 110 x 55 mm
Mass	1.05 kg

Fig. 11 provides an outline envelope of the Lunar Pathfinder Lunar Link Transponder to provide an indication of the basis for the User Terminal.

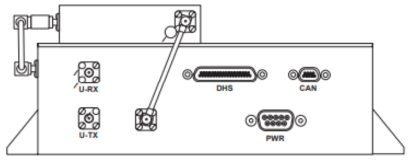
S-Band

Dimensions include top mounted filter but exclude connectors and mounting feet.



Dimensions	140 x 110 x 50 mm
Mass	1.00 kg

UHF Band



Dimensions	140 x 110 x 55 mm
Mass	1.05 kg

Fig. 11 - Lunar link transponder for LP outline

Alternatively, future service users can choose to develop their own user terminal, using ICDs provided by SSTL.

IV. Next generation of Lunar Communication and Navigation Satellites (LCNS) – ESA Moonlight Initiative

a) ESA Moonlight Initiative – Connecting Earth with the Moon

As of today, several dozens of commercial and institutional missions to the Moon are planned for the coming decades. Despite the wide variety of missions planned for the Moon, a global lunar communication and navigation infrastructure is not yet available, which implies that every individual mission will need to plan its own custom solution for communication with Earth and Earth-ranging based navigation. This is inherently inefficient. In this context, the provision of a dedicated lunar communication and navigation service is identified as a clear need and a great opportunity. This recognition lead to ESA to the proposal of the Moonlight system.

The Moonlight initiative is the fruit of a collaboration between three ESA directorates: TIA (Telecommunication and Integrated Applications), HRE (Human and Robotic Exploration) and NAV (Navigation). Moonlight LCNS will capitalise from the Lunar Pathfinder satellite, which, as early as 2024, will provide both a proof of concept for Lunar communications and an early demonstrator of the use of GNSS technologies on lunar orbit. Then, the Moonlight LCNS infrastructure will follow. Planned to be commissioned in 2027, the Moonlight system is conceived to be scalable enlarging with time its service coverage and overall service availability in line with the user needs evolutions.

For ESA, the vision for the future Moonlight infrastructure is clear:

- Enable the efficient exploration and utilization of the Lunar environment by creating telecommunication and navigation services for the Moon
- Create a constellation of lunar satellites end to end system providing services to be used by different international and national teams, both institutional and commercial
- Gain knowledge to pave the way for missions to Mars and beyond
- Support the European space industry to innovate and create lunar services and technologies, thereby boosting its competitiveness, creating jobs and prosperity
- Strengthen the relationships between ESA, NASA and other international partners, with the potential to increase resources for science and exploration, enabling new missions, science and business applications
- Engage with media and inspire the next generation of scientists and engineers

The Phase A/B1 study has 3 parallel objectives:

- User needs: Consolidate a set of relevant User requirements for COMs and NAV services on and around the Moon
- Technical solution: following the classic Phase A/B1 study structure, one of the objectives is to define the Moonlight infrastructure, capable of providing highly performing navigation and communication services to all lunar assets.
- Business / Partnership solution: in parallel to the technical solution, a group of business partners is working with ESA to define a commercial partnership structure for the development phase of Moonlight

The timeline of the study is consistent with those objectives. Started in April 2021, it has just under 17 months to bring its conclusions to ESA on time for decision at the next ESA Council of Ministers at the end of 2022.

b) SSTL Lunar constellation ambition and approach

In response to ESA's call for interest for the Moonlight initiative, SSTL Lunar has put together a strong industrial consortium, which has been awarded one of the Phase A/B1 parallel studies. The industrial consortium includes SSTL, Airbus Connected Intelligence and Space System, SES, GMV-NSL and Goonhilly Earth Station. With recognized skills and expertise throughout the value chain, from Earth ground segment to lunar surface segment, going through Earth and lunar space segments, the consortium is currently working on the early design of an infrastructure capable of providing high performance navigation and communication services to lunar assets. Starting from user's needs and requirements, the solution will need to not only offer an adequate service to users, but also to integrate and inter-operate with other elements of the lunar ecosystem, such as the Lunar Gateway or NASA's LunaNet [3].

Joined by the company KBR, the consortium is also working on the business element of the overall solution. Building on the experience acquired through Lunar Pathfinder and early CLMSS service provision, the consortium shares ESA's ambition to create a commercial service around the provision of lunar communication and navigation services. In parallel to defining the technical solution, the consortium is also building a business case and defining a commercial partnership model which, if successful, could be selected by ESA for implementation.

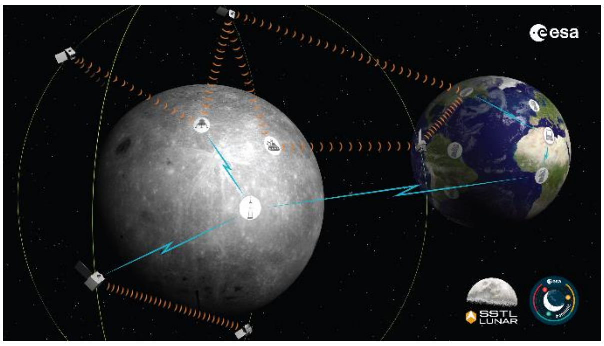


Fig. 12 - Moonlight artist illustration - SSTL Lunar

V. Conclusion

Lunar infrastructure is at the cross-roads of two of the favourite topics of the 2021 conferences and webinars: our imminent return to the Moon and collaboration between institutions and industry, for the creation of services that are not quire commercial yet, but are aspiring to be. It also constitutes of the main aspect of the current vision of the Moon Village infrastructure.

With Lunar Pathfinder, ESA and SSTL are following the same trend observed between NASA and the CLPS providers: a commercial partnership where the role of the institution is to enable to industrial partner to develop an infrastructure, with the reassurance of a minimal level of usage and therefore return on investment.

The success of Lunar communication and navigation services, and lunar infrastructure in general, will depend on the success of the return to the Moon of course, but also on our ability to collaborate and collectively create a support network, capable of supporting the lunar missions and each other.

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