CELESTIAL

Deep Space Communications

Agenda

Inspiration
Problem & Solution
Market
Technology
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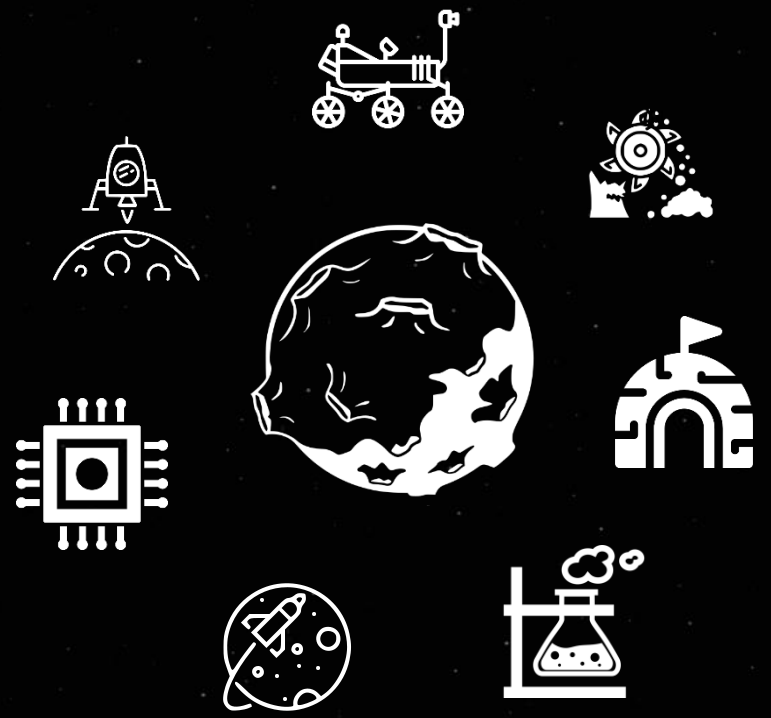
Management

Inspiration: The race to the moon

Missions



Challenges

- Accessibility for SmallSat missions
- Communication back to earth
- Establishing lunar gateway / economy

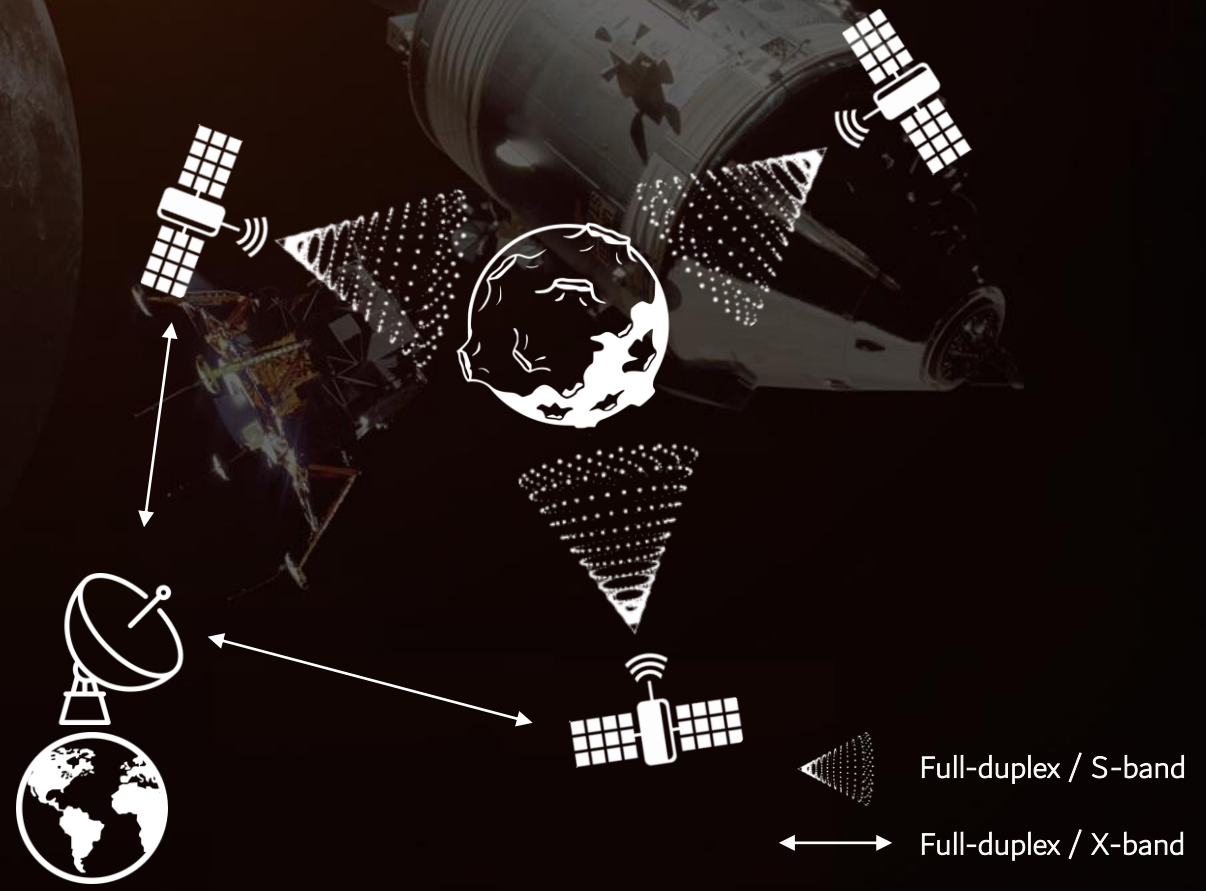
55+ commercial & exploration lunar missions planned > Emergence of a lunar economy

Vision: Lunar communication infrastructure

Mission statement

Celestial will provide the communication infrastructure required to sustain ongoing and future activities to realize the vision of a (cis-) lunar economy and permanent human settlements on the moon.
This will be realized through a Data Relay Satellite Constellation which will act as an intermediary node that connects the lunar spacecrafts and earth ground stations, lacking a direct line of sight, to realize a communication link.

Constellation Architecture



Technology transfer to earth applications

The communication satellite constellation is targeting a future commercial lunar economy.
For this, Celestial develops radio-communication technology only, not proprietary satellites.
Meanwhile, the underlying core technology is also relevant to various earth applications:

Mobility

Military

Networks

Space industry

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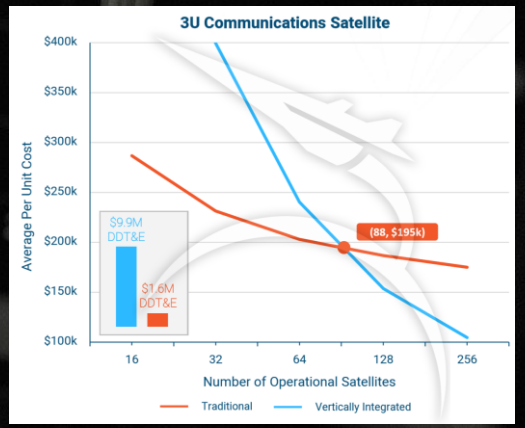
Satellite industry market trends

Satellite communication

Until now, all proposed satellite constellations amount to 25,000 small satellites. 92% of these will be used for communication. Upcoming LEO and MEO broadband satellite constellations will provide internet and connectivity on earth. These individual satellites will not be fixed, relative to ground stations. To receive continuous coverage from the constellations, ground segment antenna need to be able to track and automatically acquire signals from multiple satellites.

Satellite manufacturing

Satellite manufacturers have to decide between in-house manufacturing, vertically along the supply chain, and outsourcing satellite manufacturing.



This decision is based on economics. In-house manufacturing becomes cheaper for companies planning big (> 88 satellites) missions. Smaller missions usually prefer external suppliers.

LEO: Low Earth Orbit
MEO: Medium Earth Orbit

References: [Euro-17], [Euro-18], [Space-18], [Swe-18], [12]

Problem

Currently available small satellite communication hardware is not effective enough to adapt to all potential variations in mission signal processing and communication characteristics.

Realizing the full potential of the promised broadband satellite networks based on the planned, non-fixed, small satellite mega-constellations requires an intelligent antenna system, capable of signal tracking and automated signal acquisition.

Satellite communication solution

Communication system and patch antenna

The communication system and patch antenna are integrated by LEO and MEO EO satellites. They enable the satellite to send telemetry, telecommand, and observation data to ground stations and receive commands.

A communication system with multiple channels supports variable signal processing standards. Therefore, it is capable to communicate with different ground stations. Further, in-orbit configuration capability allows for remote control of operational characteristics such as the transmission frequency.

A broadband antenna, operating under multiple central frequencies complements the communication system. For both, reduced size and low power requirements suits small satellites. The reduced size allows for deployment of multiple antenna, thus enabling multiple communication links.

LEO: Low Earth Orbit
MEO: Medium Earth Orbit
EO: Earth Observation

Mobility applications solution

Phased Array Antenna

An array antenna consists of multiple radiative antenna elements (e.g. patch) arranged to an array. Embedded electronics and tailored software allow for electronic control of the system.
The resulting Phases Array Antenna (PAA) is capable of electronic beam steering and beam forming. This improves system isolation by minimizing the signal interferences. Further, the need for mechanical steering of the antenna is eliminated, contrary to parabolic dish antennae. This allows the PAA to track and automatically acquire signals from non-fixed LEO satellites. With this capability, the PAA can be used in mobility applications, i.e. moving airplanes, ships, trucks. As a result, seamless and continues coverage from LEO constellations can be achieved.

LEO: Low Earth Orbit
MEO: Medium Earth Orbit
PPA: Phased Array Antenna

Backhaul solution

Phased Array Antenna

Low frequency Phased Array Antenna (PAA) can function as base stations used for wireless backhaul in 5G networks. With their beamforming capability and low range, they function as high capacity and low latency micro cells. PAA based microcells can be integrated seamlessly into urban environments. The network they build is the infrastructure that provides continues connectivity to devices and vehicles. Further, this urban microcell network connects to out-of-city macro cells. These cellular towers with long range transmission capability route IT services.

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Satellite communication market

Size estimate

7,000 microsatellites are estimated to be launched by 2027 as part of EO and communication constellations. Based on the targeted product pricing, this amounts to a market size of 200 M EUR. Out of those, the addressable market are the 1,250 single satellite missions. Each mission is a prospective customer. Launches project an average annual market growth of 19 %.

References: [Euro-17] [Euro-18]

Target segment

The market strategy will be to stay high upstream focused. This way, both, vertically integrating and outsourcing manufacturing strategies of customers can be addressed. Nonetheless, the primary targeted and high relevant customers are single satellite missions and small constellations. This will also make Celestial independent of the mission success of individual big and key customers. Further, deep space missions and launch vehicles are additional targeted sectors.

EO: Earth Observation

Customer field study

Target

The Celestial team is conducting an ongoing customer field study. For this, three customer relevance categories have been defined:
High: System integrators, SMEs developing own satellite for own mission
Medium: OEMs, companies developing subsystems and satellites for other companies
Low: Prime, corporates with significant flight heritage and in-orbit missions

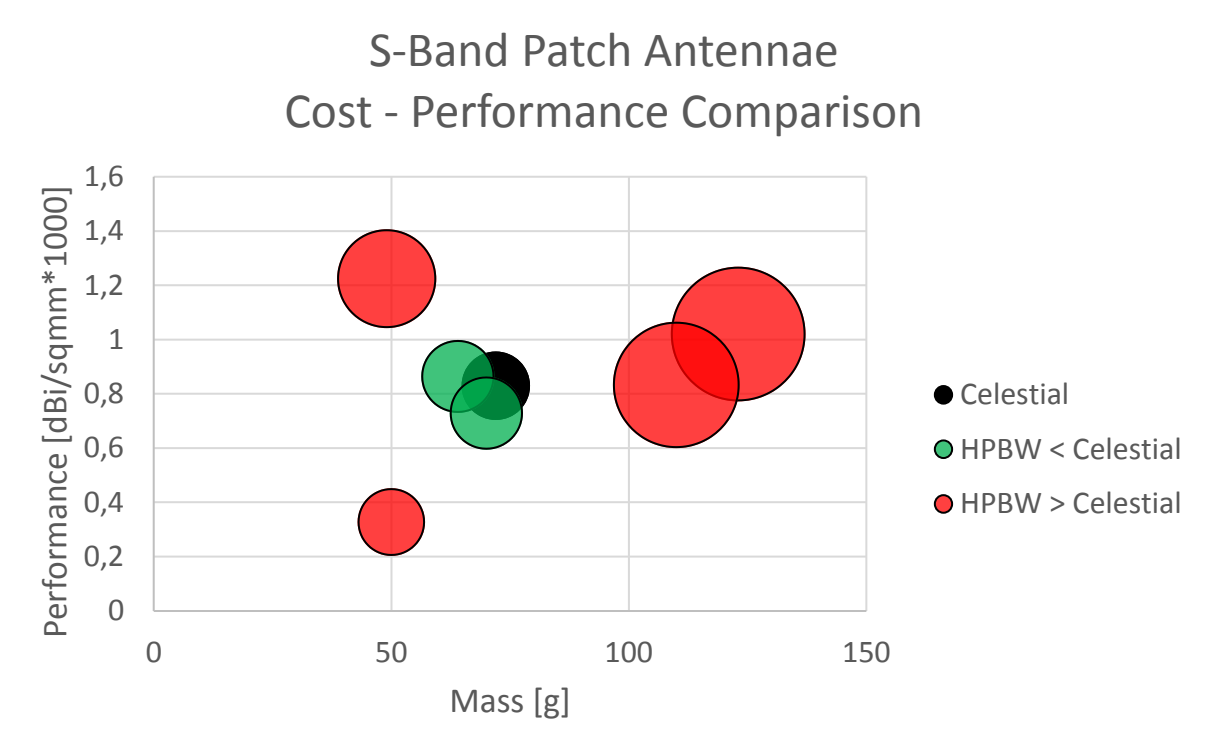
Approach

Information is requested in five key aspects, to learn from customers. These are technology, mission, supplier management, internal structure, and follow up opportunities. Based on the survey, Celestial can form strategies for marketing, customer acquisition, and customer management . As a result, first LoIs have been signed, including statements like:
"...planned SDR-based communication system is competitive, and we will certainly consider it as soon as we are going to buy...".

LoI: Letter of Intent

Competition analysis: Patch antenna

Benchmarking



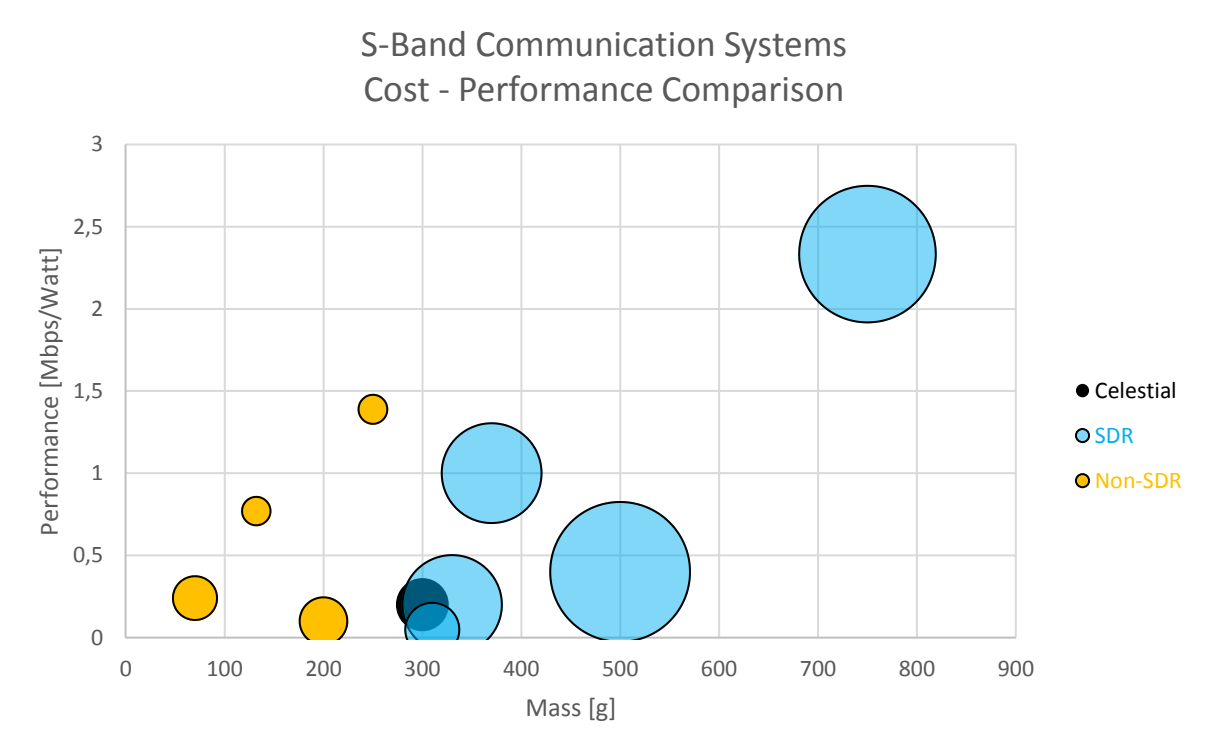
Comparison

The diagram plots antennae according to performance (Y-axis), mass, (X-axis), and price (bubble size). Performance is defined as the antenna´s capability to increase the signal strength relative to it´s size. Benchmarking reveals that Celestial´s antenna offers a highly competitive price/performance ratio. It´s performance/size ratio is ideal for the target segment. Higher performance antennae are bigger and higher priced, thus suitable for bigger satellites. Mainly the (HPBW), i.e. the signal transmission angle, offers scope for improvement.

HPBW: Half Power Beam Width

Competition analysis: Communication system

Benchmarking



Comparison

Traditional, non-SDR based systems are typically low weight, low cost, at varying performance. SDR-based systems are typically heavier and significantly more expensive. Moreover, a bigger and premium priced system can provide a significant performance increase. Celestials system is comparative in size and price to traditional communication systems yet also offers in-orbit configuration capabilities. These capabilities are typically only available in bigger and more expensive systems. Therefore, Celestial´s communication system will be highly competitive within it´s target segment.

Phased Array Antenna market

Mobility applications

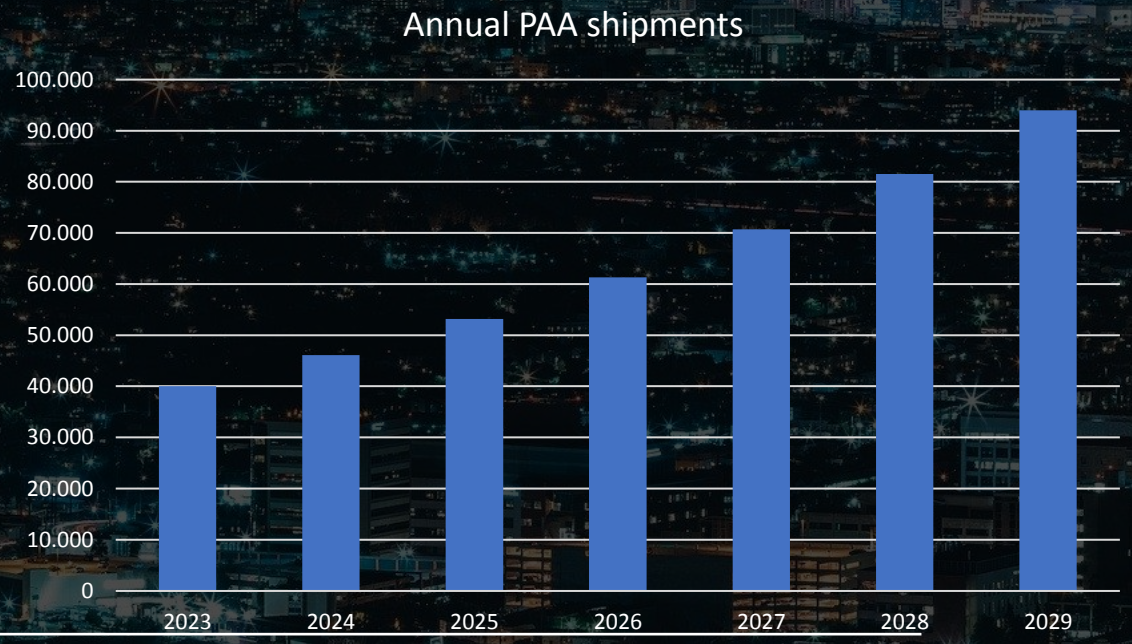
Projected cumulative PAA equipment sales for the next decade represent the total available market. This market is dominated by applications in government and commercial aviation. Consumer application shipment of low-price PAAs dominate shipment volume.

Projection in Billion EUR	Cumulative until year
7.73	2026
6.71	2027
9.34	2028
10.19	2029

References: [1] [2] [3] [4] [5] [6] PAA: Phased Array Antenna

Enterprise and backhaul

The expected cumulative equipment revenue for this emerging sector is at 141 M EUR by 2029. PAA shipments are projected to grow annually by 15.5 %.



Competition analysis: Phased Array Antenna

Competition analysis

During the recent years, multiple companies (e.g. C-COM, Kymeta, Phasor, ThinKom a.o.) have announced their plans to bring PAAs to the market. The main challenge has been to develop and manufacture PAAs at a price acceptable to enterprise customers. PAA developers follow individual development approaches and have individual technology breakthroughs. However, different PAA configurations are expected to be successful in different markets.

References: [7] [8]

Target segment

The currently existing market for PAAs is the government and commercial aviation sector. Especially the military sector has been an established niche market over the past years. These sectors will be targeted for a customer study first. Subsequently, a pilot project will be prepared. Upon refinement of the PAA, the satellite communication ground segment and backhaul sector will be targeted when the sectors are established markets.

PAA: Phased Array Antenna

Distribution channels

Online

Market platforms

Celestials plans to leverage satellite subsystem online market platforms (e.g. cubesatshop.de, satsearch.co) for sales and customer acquisition.

Celestial website

The Celestial website will highlight the offered products. The User Interface will be optimized to encourage visitors to contact the team to initiate a conversation and thus generate leads.

Offline

Trade fairs

Events like industry specific trade shows are traditional sales channels which will also be utilized. Celestial will present the products in front of an expert audience and use networking opportunities the establish business partnerships.

Distribution partners

Individual distribution partnerships will be targeted. These are resellers of subsystems, launch services, companies offering manufacturing and design services, and industry consortiums.

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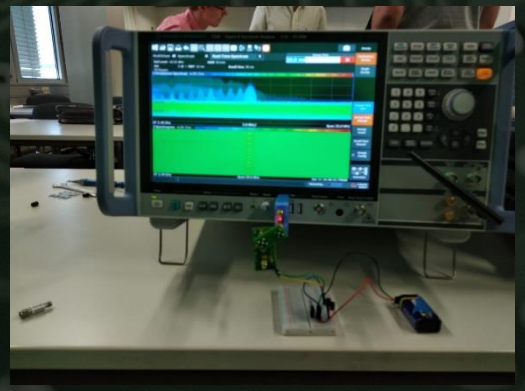
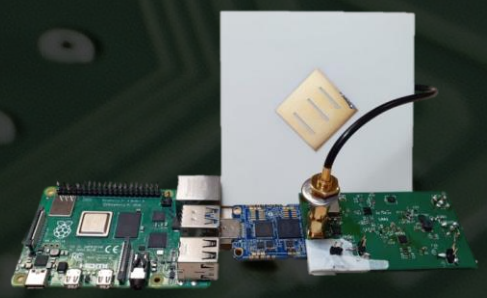
Technology development

Communication system

Celestial developed functional hardware prototypes for the communication system. The development was done completely in-house. This includes the mathematical concept, functional design, component and material selection, component integration, laboratory testing, and firmware development. This means, the resulting technology is proprietary to Celestial. The prototyping was completed by Celestial in a Makerspace and by using external manufacturing service providers. In the future development steps, the SDR will be replaced by a proprietary FPGA integrated microcontroller. After the selection and integration of space grade components, an in-orbit demonstration will follow.



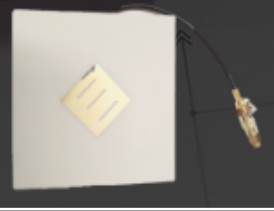




Technology development

Patch antenna

An MVP of the patch antenna has been produced. The antenna is full duplex (sending & receiving) and used for CCSDS Telemetry, Tracking and Command (TT&C). Gain, farfield results, VSWR, S parameters, Smith Chart, axial ratio, radiation and total efficiency, and power have been verified in simulations and laboratory tests. Some performance characteristics are listed in the table. The next step will be the result validation in an anechoic chamber. A partner with a suitable testing facility has already been found. After a subsequent radiation shielding coating the antenna is ready for in-orbit operations and market introduction.

Characteristics	Performance
Operating frequency (GHz)	2.05 – 2.2
Central frequency (GHz)	2.05
RHCP Gain (dBi)	7.97
VSWR	<2
Bandwidth (MHz)	215
Return loss (dB)	-15
Beam angle (Deg.)	75
Polarization	RHCP/LHCP
Connector type	SMA
Dimensions (mm)	98 x 98x 3.22
Mass (g)	<100



MVP: Minimum Viable Product

Analog mission & technology demonstration

The technology's functionality and performance has been demonstrated during the IGLUNA 2020 analog mission [9]. During the 1-year project duration, the technology was developed under ECS standards and reviewed by independent experts. During the live demonstration, a fully integrated system of hard- and software was shown. Various signal processing and remote configuration tests have been performed successfully. The demonstration included the integration with space industry partner solutions. The project was one of the top three teams awarded with the space award [10]. As a result, Celestial was able to pitch the project in front of the ESA Director General [11].

References: [9] [10] [11]

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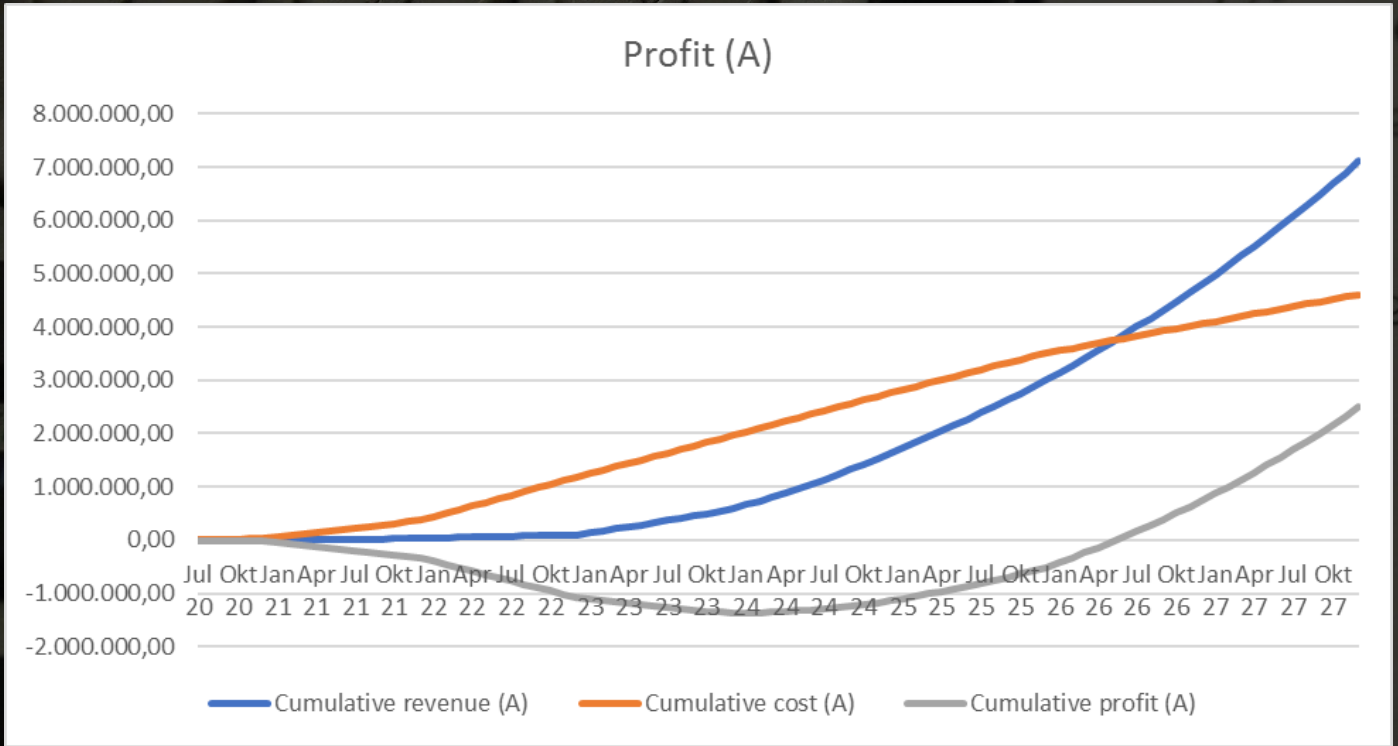
Revenue model

Market entry	Product	Unit price [€]	Unit sales	Revenue [€]
Jan 2021	S-band patch antenna	2,200	162	356,400
Oct 2021	X-band patch antenna	2,200	134	294,800
Jan 2023	PAA for mobility applications	30,000	134	4,020,000
Jan 2024	Communication system	25,000	68	1,700,000
Jul 2024	PAA for fixed applications	10,000	57	570,000
Jan 2026	PAA for enterprise backhaul	4,000	27	108,000
		Total	582	7,049,200

Celestials sales growth projection is based on research on the projected Cumulative Annual Growth Rate (CAGR) for the respective market. In order to anticipate deviations from the market growth projections and sales performance of Celestial, different sales projections will be considered. Scenario A is based on the projected CAGR. Scenario B and C expected Celestials sales performance to be at 120 % and 80 % respectively of that CAGR. The projected unit sales and revenue is cumulative until the end of 2027.

Profit model

Projection

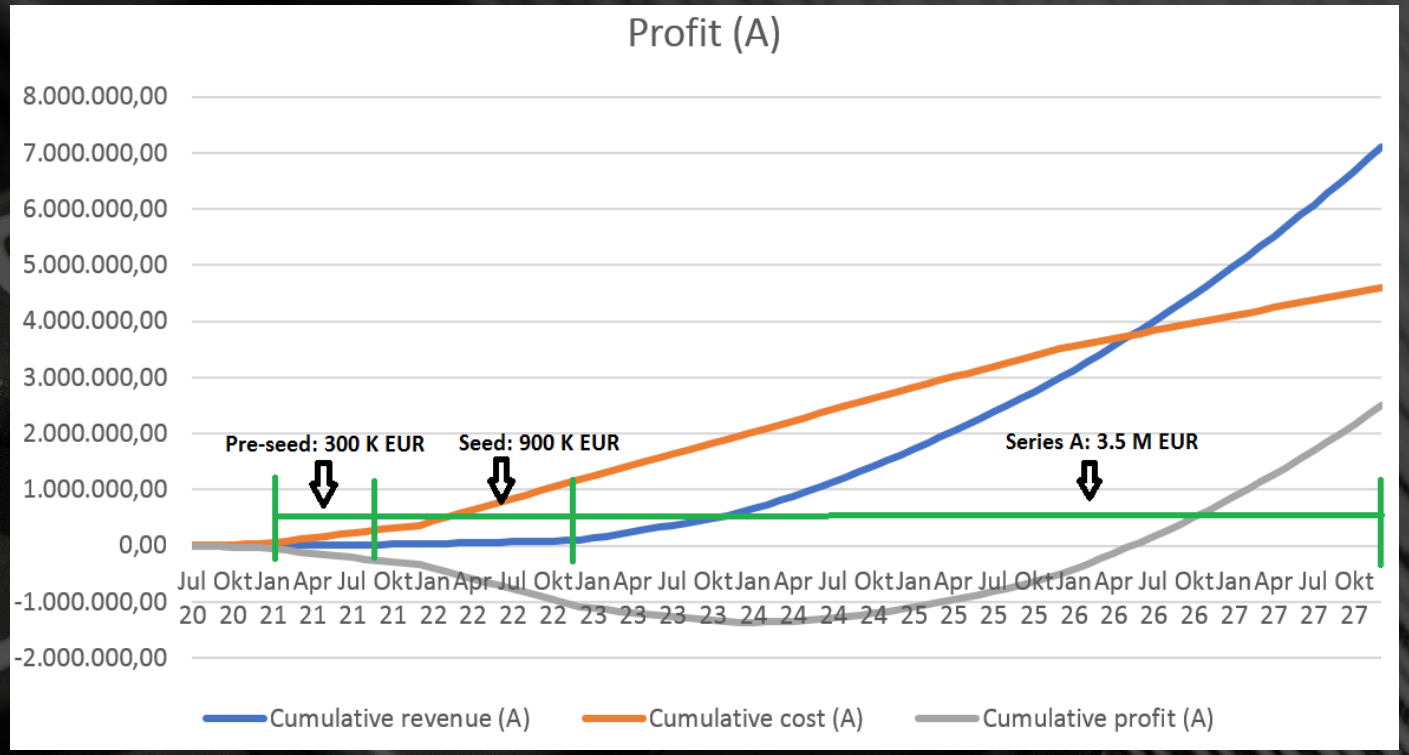


Key numbers

Profitability in January 2024
Invest until profitability: 2.0 M €
Break even in June 2026
Invest until break even: 3.8M €
Until 2028:
7.1 M € in cumulative sales
2.5 M € in cumulative profit

Funding model

Phases



Usage

The pre-seed investment will be spent on development and market entry of the X-band patch antenna. Further, it will be used for hiring and beginning development of PAA. The seed investment will be used for development and market entry of the PAA for mobility applications.. The series A investment will be used for development and market entry of further PAA products, the communication system and growing the company.

PAA: Phased Array Antenna

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Project milestones

05/2018	Team formation at ActInSpace Hackathon in Berlin
11/2018	Start Gründerwerkstatt Adlershof incubation program incl. founders grant (Berlin)
02/2019	Start Astropreneurs acceleration program with CESAH (Darmstadt)
03/2019	Start XPRENEURS acceleration program from UnternehmerTUM (Munich)
05/2019	Receiving prototyping grant from Initiative for Industrial Innovators (Munich)
06/2019	Start of SpaceTech South West Incubation Programme (Exeter, UK)
07/2019	Winning 3rd place in INNOspace Masters 2019 - OHB challenge
08/2019	Prototype 1 of communication system finished
09/2019	Selection as participating team for IGLUNA 2020, with TU Berlin
02/2020	Prototype 2 of communication system and patch antenna finished
06/2020	Celestial registration as limited liability company in Nuremberg, Germany
07/2020	Start of ESA BIC Bavaria incubation program (Nuremberg)
07/2020	Successful technology demonstration and winning IGLUNA 2020 space award

Organizational structure and partner

Structure

Celestial is a GmbH registered in Nuremberg (HRB 37759). In parallel to the office on Nuremberg, the team is also present in Berlin. The two founder and MD´s hold 50 % of the company each. Two additional master level students from TU Berlin support development. The project has been part of several support programs and successfully completed the IGLUNA 2020 analog mission. Various partners support Celestial in different areas.

Partner

Engineering

R&D

Production

Business

Missions

Funding

A team of visionaries

Mayank
Aerospace engineer
Managing Director

Johannes Schumacher
Manufacturing engineer
Managing Director

Ravneet Kaur
Aerospace engineer
Antenna design

Udit Sahoo
Aerospace engineer
Business development

Dr. Zizung Yoon
TU Berlin
Technology mentor

Klaus Kammermeier
Innovation Labs Berlin
Business mentor

Gaetan Petit
Swiss Space Center
Business mentor

Activities and outlook

R&D / Production

Current activities aim to set up the value chain for patch antenna production. Afterwards, R&D will focus on PAA. The targeted PAA applications are in terrestrial mobility and deep space.

Business development

Current activities aim to set up the distribution channels for patch antenna sales. In parallel, a market study for PAA is being initiated to guide R&D.

Project development

Reaching future goals requires investment. 50 K EUR will expedite the patch antenna market introduction. Starting in 2021, 300 K EUR are required to continue antenna R&D.

Pilot projects

For the patch antenna, an in-orbit technology demonstration is targeted. The related flight heritage will significantly help sales. In parallel, a PAA feasibility study is targeted.

PAA: Phased Array Antenna

Summary

Vision	Communication infrastructure for more than 55 upcoming lunar missions
Problem	Non-adaptive small satellite communication hardware
	Required intelligent antenna system for broadband satellite networks
Solution	Communication system with multi-channel, variable signal processing standards
	Patch antenna operating under multiple central frequencies
	Phased Array Antenna capable of signal tracking and auto-acquisition
Market	7,000 projected microsatellites, 19% p.a. market growth, targeting small missions
	Cumulative equipment revenue of 141 M USD, shipment CAGR 15.5 % by 2029
Competition	Highly competitive antenna, high performance transceiver, low-cost SDR system
Partner	International space engineering partners, Bavaria based production partners
Team	Space engineering background, diverse industrial experience, mentor support
Achievement	INNOspace masters 2019 3rd position, IGLUNA 2020 Space Award winner
Next	In-orbit technology demonstration by the end of 2020

CAGR: Cumulative Annual Growth Rate

Moon Is For Everyone!

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