Multipurpose S, X & Ka Band TT&C Antenna System for MEO, GEO and Lunar Communications

Andrea Calleri[a], Matthias Reichert[a], Thomas Pleines[a]

[a] *OHB Digital Connect GmbH, Weberstr. 21, Mainz, Germany 55130*
andrea.calleri@ohb.de, matthias.reichert@ohb.de, thomas.pleines@ohb.de

Abstract

The moon is attracting renewed attention leading to a number of intended future missions. As a result, the demand for ground based communication infrastructures is increasing. As a ground segment provider, OHB Digital Connect GmbH has developed and designed a tailor-made multipurpose S, X & Ka Band TT&C antenna suitable for MEO, GEO and lunar communications. The system is able to support communications during all the different mission phases such as: LEOP, MEO and GEO orbits, flights between the earth and moon, as well as moon orbits, landings, and surfaces. Furthermore, the system is capable for expansions to support long distance communications foreseen for Mars and/or deep-space missions. The antenna system is capable of carrying a variety of feed configurations up to a three band Rx/Tx feed system for S, X, and Ka-band, providing full telemetry, tele-commanding and ranging capabilities for all bands. This modularity enables a broad range of use and flexibility to meet ground station operators' needs. This presentation provides a full system description, focusing on the RF requirements and the flow-down to structural and electro-mechanical subsystem design.

Keywords: Communication antenna, lunar communication, ground station, multi-band feed

Acronyms/Abbreviations

Azimuth (AZ)
Components-off-the-shelf (COTS)
Elevation (EL)
Geostationary earth orbit (GEO)
Graphic user interface (GUI)
Heating, ventilation, and air conditioning (HVAC)
High power amplifier (HPA)
Launch and early orbit phase (LEOP)
Low noise amplifier (LNA)
Medium earth orbit (MEO)
Motion and control (M&C)
Radio Frequency (RF)
Real time environment (RTE)
Telemetry, tracking & command (TT&C)
Static pointing error model (SPEM)

1. Introduction

The upcoming years will be affected by several manned and unmanned missions to the moon. Crucial for a mission's success is the capability for reliable communication between the spacecraft and the ground segment. Existing infrastructure broadly fulfills the demands of established mission concepts like medium or geostationary earth orbit (MEO, GEO). Many institutional and commercial service providers are established. Infrastructure for missions beyond those orbits is already more sparse due to sophisticated technical requirements and accompanied capital demands. In the coming years, the increased demand for planned moon/mars and deep space missions will push the deep space infrastructures to the edge. Thus, a novel tailored network for moon communication shall close the gap between GEO and deep space missions.

The programmatic main drivers are the improvement of the ground segment infrastructure availability, dedicated to moon missions, guaranteeing 24/7 communication link to spacecraft, and offering an adequate data rate support for science and human exploration missions. The ground segment operator needs to focus on the reduction of the ground segment infrastructure complexity and operational costs to establish sustainable business models.

In close consultation with ground segment operators, OHB Digital Connect GmbH (OHB DC, formerly MT Mechatronics GmbH) in Mainz, Germany, has consolidated the requirements for the development and design of a tailor-made multipurpose S, X & Ka Band TT&C antenna for specific lunar applications.

2. Lunar Antenna System Overview

The demanding requirements for a reliable and efficient lunar communication link lead to specific antenna system characteristics that have been implemented in the design:

- Primary reflector diameter of 20 m to enable the required antenna gain
- High precision and stable reflector system to manage different wave lengths up to Ka-band
- Reliable and flexible control system for excellent pointing and tracking performance
- Robust and stiff structural design for operation in demanding environmental conditions
- High ratio components-off-the-shelf (COTS) for maximal availability
- Multi zone HVAC system for optimal component environments
- Minimized key hole for data link retention
- Spacious elevation cabin provides proper accommodations and accessibility for RF equipment
- Spacious pedestal tower design to provide additional space for operator’s equipment (e.g. time & frequency)
- Fully protected and safe working environment provides accessibility for maintenance and troubleshooting

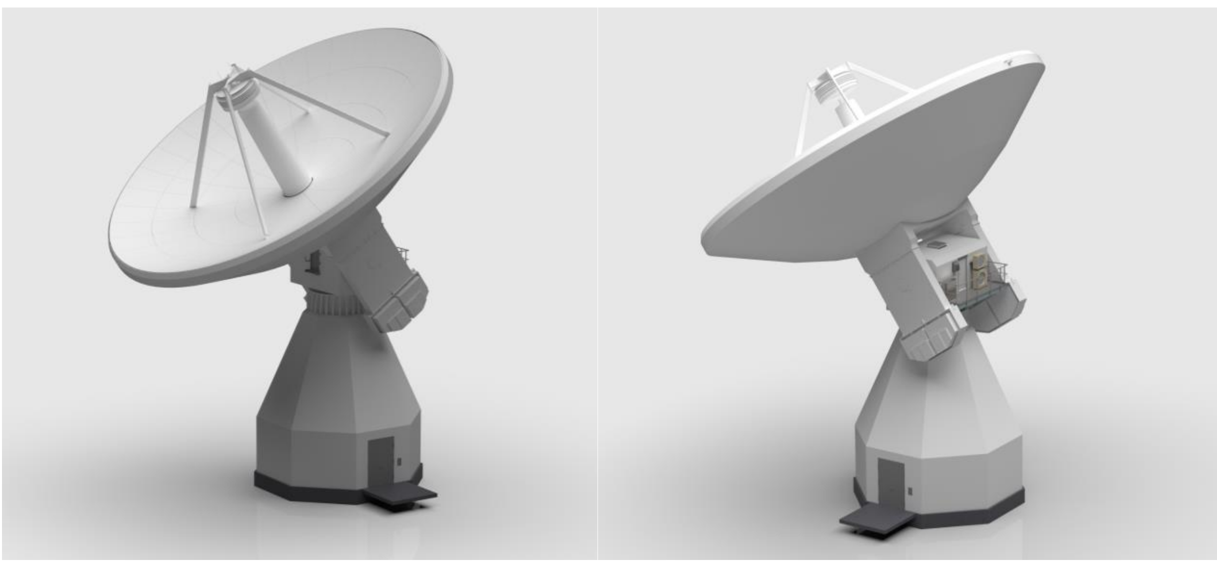

Figure 1: Lunar antenna overview

3. Electro Mechanical Design

The mechanical design focuses on high reliability and robustness, as well as modularity concerning the RF system. The structural and mechanical parts of the antenna are designed for the continuous operation of over 20 years.

The antenna layout is an elevation over azimuth turning head antenna, covering motion ranges of ± 270° in azimuth (AZ) and 0° to 90° in elevation (EL). Due to the demanding pointing requirements, the antenna rests on a concrete tower that provides plenty of space for control cabinets, operator's equipment and spare parts. The tower offers easy access to the AZ cabin and beyond, via stairs and ladders. Heavier equipment can be lifted with hoists through hatches located on the floor grounds.

The AZ cabin hosts drives for the AZ and EL axes, as well as an EL cable wrap and other mechanisms. All drives can be accessed from inside the cabin for maintenance and repairs in a sheltered environment. Outside the cabin, outdoor units for HVAC systems can be mounted and accessed through a balcony. Larger equipment, like racks, can be lifted to the balcony and moved inside the AZ cabin via the access door.

The EL cabin can be accessed in 0° EL position from the AZ cabin through sealed access doors. The EL cabin provides space to host 200 RU of space for RF equipment in controlled environmental conditions. The feed tube can be entered through a man hole from the EL cabin for maintenance and repairs of the feed horn and related equipment.

Independent of the ground station's location and operation scenarios, the main reflector back up structure can be equipped with a cladding to avoid extensive sun exposure and extreme temperatures, which can induce the deformation of the truss work. The sub reflector is equipped with an active hexapod to compensate gravitation induced relative displacements between the main reflector, sub reflector and feed unit.

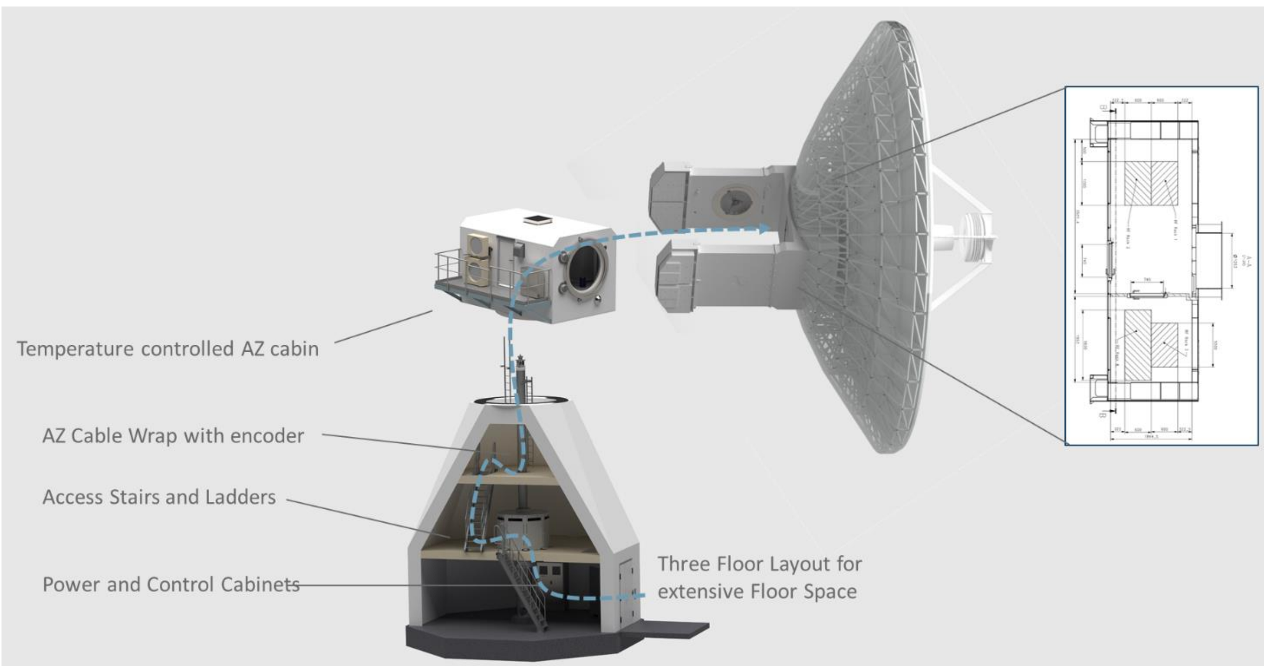

Figure 2: Antenna layout and access paths

4. Monitoring and Control System

OHB DC has established a sophisticated M&C system that can be fully integrated into the operator facility's station controller. The ACU M&C part acts as a high level monitoring and control interface for the antenna. The M&C architecture is illustrated in Figure 3. It will be connected to other local subsystems like the ACU real time environment (RTE) and other antenna equipment. It consists of different services, each handling a specific set of features. The M&C web graphic user interface (GUI) provides an aggregated entry point to the service features for operators. The HTTP API enables integration of the M&C and the underlying services with third-party systems.

The main M&C backend is a Java application and provides most of the services such as the web frontend and the HTTP API. A service handles the device connections and normalizes status data and control commands. The M&C automation engine also handles non-real-time automation tasks.

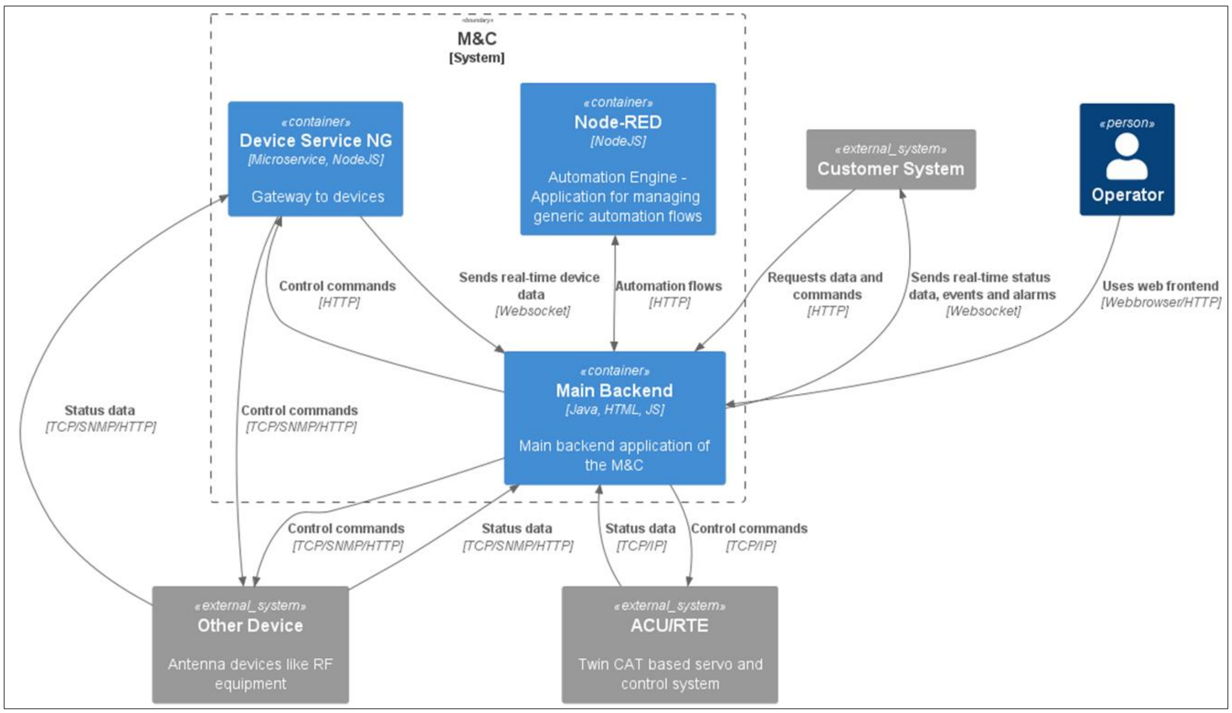

Figure 3: M&C architecture

5. RF System

OHB DC's RF system design is highly modular and suitable for up to three independent frequency bands Tx/Rx. This provides the flexibility to equip future antennas with a reduced number of frequency bands, or to extend to frequency bands such as Q- and V-band.

The reflector system utilizes a dual-mirror ring focus configuration with shaped reflectors. The main reflector diameter is 20 m, while the sub-reflector diameter is 1.84 m. The optical design was driven by the constraint of the triband feed illumination angle, the advantages of a compact design and the large utilizable area in the shadow of the sub-reflector. In general, the ring focus design benefits from smaller sub-reflector diameters and smaller feed designs compared to a Cassegrain configuration. Simulated antenna pattern show compliance to ITU-R Sa.509-3.

The elevation cabin allows the implementation of four 19-inch racks with up to 47 rack units each to accommodate equipment for three independent RF systems. Additional equipment can be placed in the feed tube, which can also be accessed from the elevation cabin for inspection and maintenance purposes.

The temperature environment in the elevation cabin and feed tube is highly stabilized to overcome frequency stability issues due to changing temperatures which impact the overall Allan deviation of the system. The system is designed to ensure precise ranging and calibration measurements in compliance to the ECSS-E-ST-50-02C and CCSDS Blue Book 401.0-B-31 category B mission recommendations.

Regarding the redundancy of components, a trade-off between cost efficiency and availability has been made under the assumption of a mean daily maintenance and repair time of 12 hours.

The current baseline implementation of S-band, X-band and Ka-band foresees a simultaneous reception in both circular polarizations and a selectable transmission in one polarization. The transmission can be done in two bands simultaneously on full power and three bands simultaneously with reduced power.

Due to the modular design, the intermediate frequencies can be adapted to fit the operator's needs without changing the overall system design.

The connection between the RF equipment in the elevation cabin and the baseband equipment, as well as the timing and frequency reference is implemented with RF over fiber optic links. This provides flexibility with the placement of the baseband equipment, timing and frequency reference. The baseband equipment, as well as the timing and frequency reference, can be accommodated in the antenna tower or in a remote control center.

6. Key Performance Parameters

Table 1 shows the RF performance parameters of the antenna while *Table* 2 outlines an overview of the mechanical performance.

Table 1: RF Performance Parameter

Parameter	S-Band	X-Band	K/Ka-Band
Receive Frequency Range	2200 MHz to 2300 MHz	8400 MHz to 8500 MHz	25500 MHz to 27000 MHz
Receive Gain	> 51.9 dBi	> 64.1 dBi	> 73.7 dBi
Receive Polarization simultaneously	RHCP & LHCP	RHCP & LHCP	RHCP & LHCP
Receive G/T clear sky, 5° EL	30.5 dB/K (ambient LNA)	41.5 dB/K (ambient LNA)	47.7 dB/K (ambient LNA) 49.4 dB/K (cryo LNA)
Transmit Frequency Range	2025 MHz to 2120 MHz	7145 MHz to 7235 MHz	22550 MHz to 23150 MHz
Transmit Gain	51.2 dBi	62.8 dBi	72.7 dBi
Transmit Polarization Selectable via Switch	RHCP / LHCP	RHCP / LHCP	RHCP / LHCP
Transmit EIRP at P_{Linear}	83 dBW Phase combined HPA with 800 W GaN SSPA Units	87.8 dBW 800 W GaN SSPA	92 dBW 400 W TWTA
Tracking Mode	Program Track Auto-Track	Program Track Auto-Track	Program Track Auto-Track
Auto-Track Method	Monopulse	Monopulse	Monopulse

Table 2: Mechanical Performance Parameter

Parameter	Specification
Type description	Full Motion Antenna elevation over azimuth
Optical Configuration	Ring focus
Main Reflector diameter	20 m
Main Reflector surface accuracy	0.15 mm RMS
Sub-reflector diameter	1.85 m
Sub-reflector surface accuracy	0.08 mm RMS
Sub-reflector positioner (hexapod)	Actively controlled
Azimuth axis travel range	±270°
Azimuth axis maximum velocity	3 °/s
Azimuth axis maximum acceleration	1.5 °/s²
Elevation axis travel range	0° to 90°
Elevation axis maximum velocity	1.5 °/s
Elevation axis maximum acceleration	1.5 °/s²
Environmental Conditions	
Wind velocity operation	≤ 72 km/h
Wind velocity survival	≤ 180 km/h
Temperature operation	-10° C to +50° C
Temperature survival	-20° C to +60° C
Humidity	0 – 100%
Rain	< 50 mm/h

7. Tracking and Pointing Performance

To achieve consistent high data links in Ka-band, high accuracies in blind pointing and tracking are required. *Table* 3 and *Table* 4 show the blind pointing accuracies as well as auto track accuracies under wind conditions.

Table 3: Blind Pointing Accuracy

No Wind	36 km/h + 10% gusts	70 km/h + 10% gusts
6.6 mdeg	9.2 mdeg	24.7 mdeg

Table 4: Worst Case Auto-Track Accuracy

Tracking Chain	Atmospheric Conditions	Accuracy with no wind (RMS)	Accuracy with wind at 36 km/h + 10% gusts (RMS)	Accuracy with wind at 70 km/h + 10% gusts (RMS)
S-Band	CD99.9	45.2 mdeg	45.2 mdeg	45.3 mdeg
X-Band	CD99.9	10.8 mdeg	10.8 mdeg	11.1 mdeg
Ka-Band	CD90	4.3 mdeg	4.3 mdeg	5.2 mdeg

The auto-track performance of the monopulse has been calculated in worst case scenarios. The results are based on a scenario in which the antenna is tracking a target close to the moon or on the lunar surface. The target is located at the center of the lunar disk, as seen from the antenna at a 5 degree elevation angle, while the moon is in its brightest phase regarding the noise temperature of the moon as derived by Morabito and Heckman [1][2].

Furthermore, the antenna system provides an automated process for the parametrization of the pointing correction model. The pointing correction model is based on a standard static/systematic pointing error model (SPEM) according to Greve et al [3]. The model provides nine coefficients to be parametrized, based on pointing measurements with corresponding natural radio sources of precisely known position. A (grid) scan of the area around these objects allow the determination of the pointing deviation. Thus, the whole process of measurement – evaluation – parameter adjustment is reduced to a single calibration effort once the antenna is fully commissioned.

8. Conclusions

Filling the gap from common LEO, MEO and GEO antennas to large high performance, deep space ground stations are crucial to provide reliable communication capabilities for upcoming missions. OHB DC has developed a robust and stiff 20 m multipurpose antenna design to close that gap. The demanding performance requirements for moon mission applications flow down to high performance goals for the antenna system.

The main results are:

- Full compliance with Category B Mission requirements ECSS-E-ST-50-02C and CCSDS 401.0-B-31 Blue Book
- High modularity concerning feed configuration up to tri-band feeds (S/S/X/X/Ka/Ka)
- High G/T and EIRP achievable
- Robust and stiff mechanical for high pointing performance
- Easy accessibility of all mechanical and RF systems for maintenance and repair to guarantee high availability
- Thermal controlled environment with high stability for critical RF components
- Critical RF components are located close to feed system for minimal signal losses

In the upcoming months, extensive discussions with ground station operators and component suppliers for optimal RF configuration will take place to evaluate further future mission requirements and adapt the design accordingly.

References

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