Executive Summary Report

GSTP-04

TRI-BAND (S/X/K) FEED SYSTEM DESIGN FOR FUTURE EO MISSIONS – GT11-012GS

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HISTORY OF CHANGE

Version	Author	Date	Comment
1.00	T. Mathes	14/12/2022	First release.

APPROVAL OF DOCUMENT

	Role	Name	Signature	Date
Prepared	System engineering	T. Mathes	/	/
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1 PROJECT DESCRIPTION

1.1 PURPOSE AND SCOPE

Nowadays, Earth Observation (EO) missions operated by ESA mostly use S-band for TT&C and X-band for data downlink. EO satellites currently operate the downlink of the payload data in the Earth Exploration Satellite (EES) X-band (8025 - 8400 MHz) with data rates in the order of hundreds of Mbit/s.

With the ever-increasing sophistication of on-board instruments, it is foreseen that in the near future EO satellites will require downlink rates of more than one Gbit/s for their payload data, thus largely exceeding the available download rates in the currently used X-band slots. In parallel, there is a rapidly growing congestion of the X-band due to the high number of missions operating in this frequency band. Furthermore, most EO missions are characterized by low altitude polar orbits leading to very short visibility times of the satellites over the ground stations, which are mostly co-located at high latitudes and thereby further increasing the risk of interference.

A mitigation of the above problems is the migration of the payload data channels to the 25.5 - 27 GHz K-band, which has been allocated to Earth Exploration Satellite (EES) services at the ITU World Radiocommunications Conference (WRC) in the past. Furthermore, X-band will in the future be used beside S-band and eventually replace it for TT&C services with the use of the extended uplink band of 7145 - 7250 MHz.

During the transition period from S/X-band to S/K-band or X/K-band, it will be beneficial to have access to ground station antennas supporting the 3 frequency bands in parallel. The supporting ground stations will have to be provided with equipment capable of supporting these new bands simultaneously to the currently used ones to guarantee back-compatibility with running missions. Regarding the electro-mechanical part of such S/X/K-band antennas, the accuracy requirements are driven by K-band, whereas space and RF power handling requirements are driven by S- and X-band. More elaborate solutions need to be provided for some key elements of the antennas, which is why ESA has launched a series of studies under its General Support Technology Program (GSTP) in view of confirming the feasibility of such tri-band ground stations.

One of the key elements is the technically challenging feed and optical system which is foreseen to work in transmission mode for S- and X-band and in reception mode for S-, X- and K-band. Furthermore, the horn and combining network shall support the auto-track capability for all three receiving bands of operation in one selectable circular polarisation. Complementary to the feed system a large amount of active RF components (such as LNAs, frequency converters and HPAs) and interconnections need to be integrated in or near the antenna.

Since 2008, the Agency has carried out several studies to prepare for the future use of the 26GHz band for the Data Downlink of Earth Observation Satellites. Mainly two system architectures were investigated with different antenna diameters on board and on ground. For the ground segment, antennas in the 6 to 7m range were considered in one case and in the 13 to 15m range in the other case.

In that context, HITEC together with MIRAD had carried out a design study in 2012-2014 called "Design of a S/K-Band ground station antenna (13-15m aperture) for LEO applications".

In order to provide a versatile and future-proof ground infrastructure, enabling the transition to the higher bands, the goal of this activity, executed jointly by HITEC Luxembourg and MIRAD Microwave, is thus to develop both a 14m and a 6.8m tri-band (S/X/K) ground station, able to support all TT&C and data downlink combinations as described above. The 14m antenna is derived from the 14m antenna from the previous study whereas the 6.8m antenna is derived from an existing HITEC product.

1.2 STARTING POINT

The work in this study was largely enabled by re-using heritage solutions available in the consortium at the beginning of the study.

S/K-Band 14m 3-axes full motion ground station antenna, as developed jointly by HITEC Luxembourg and MIRAD Microwave in a prior GSTP study: the electro-mechanical design of this antenna, based on an AZ1/AZ2/EL mount, was entirely re-used, such that the associated performance data was not affected. The RF system design, with the active components, equally constituted the baseline for the S- and K-band subsystems of this study.

HITEC Luxembourg's 6.8m 3-axes full motion ground station antenna: initially developed for a governmental customer, HITEC has deployed a 6.8m antenna system for an Earth Observation application. The antenna system, featuring a ring focus optics, supports TT&C in S-band and data downlink in X-band. It is equipped with a TILT/AZ/EL mount to support LEO satellites. This antenna system served as baseline to investigate the possibility to integrate tri-band capability in a 6.8m antenna system for EO applications.

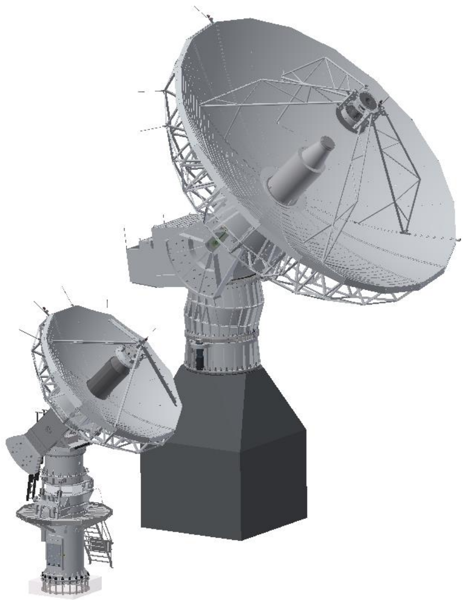

Figure 1-1: S/X-band 6.8m and S/K-band 14m 3-axes full motion antennas

MIRAD's S/X/K tri-band feed: MIRAD has developed and built a S/X/K-band feed with tracking capability in all 3 frequency bands for DLR, Neustrelitz. An enhancement thereof with tracking capability in both S- and X-band is currently under development for DLR. The concerned feed combiner design is considered BIPR and thus not subject of the present study. However, the corresponding feed characteristics were used for the investigations and design works of the present project.

The above elements allowed containing the development effort required for the present study and limited the technical risks. Major developments were limited to the definition of a suitable optics, i.e. the combination of reflectors with the feed horn, and the physical integration of all associated components inside the feed and antenna to ensure both performance and maintainability.

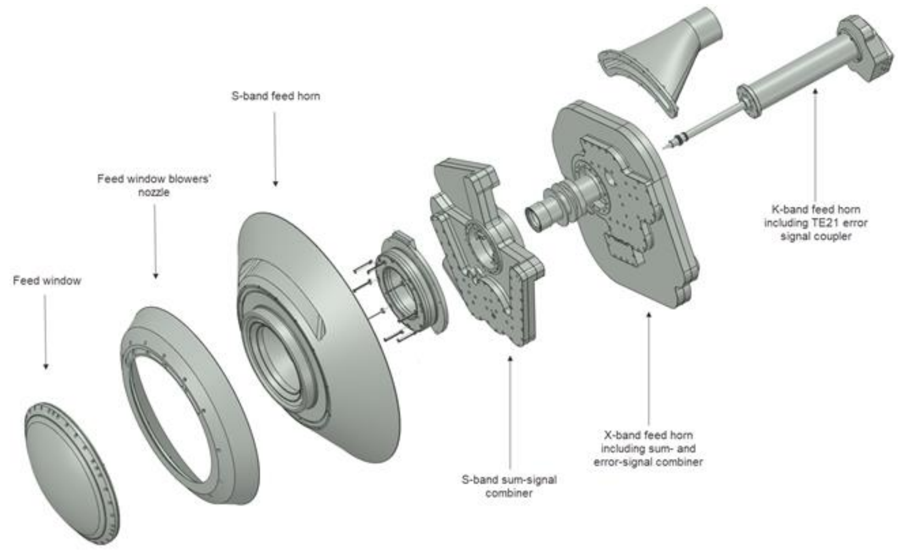

Figure 1-2: Exploded view of the S/S/X/X/K-feed with the nested coaxial triband feedhorn design

1.3 STUDY LOGIC

Taking into account both HITEC's and MIRAD's heritage described in the previous section, the project was organized in 4 phases:

1. Initial System Analysis
2. 14m System Design
3. Versatility Analysis
4. Performance Verification

During the **Initial System Analysis**, it was investigated how the tri-band capability could be integrated in the 14m antenna design developed during the prior GSTP study. It was relatively clear that the feed horn would consist of three coaxial, axially corrugated low-gain horns rather than of radially corrugated high-gain horns as was the case in the dual-band design from the former study. Therefore, a new ring-focus reflector system was required instead of the prior Cassegrain optics. Furthermore, physical integration aspects were investigated. This concerned the integration of the three combining and switching networks inside the tubus, the active RF components throughout the antenna and the interconnections.

During the **14m System Design**, the ring focus optical design was finalized and the corresponding performance determined. The BIPR tri-band feed design was further analyzed to provide performance characteristics for the antenna budgets. Likewise, any new RF components, e.g. for X-band, were specified and included in the RF budgets.

The **Versatility Analysis** covered two aspects: first, it was evaluated if the tri-band feed and all associated active components could also be integrated into the 6.8m antenna. The same system architecture as for the 14m antenna was to be maintained, but expectedly integration and maintainability aspects were more critical. Then the different possible dual-band configurations were derived from the tri-band design.

As part of the **Performance Verification**, the final feed design and final optical design were reconsidered in more detail and some additional analyzes were performed. The available parameters were used for the final compliance statement to the requirements.

Considering the heritage and BIPR, neither breadboarding nor testing were foreseen in this activity.

Throughout the study the analysis and design of the 14m and 6.8m antennas were largely executed in parallel.

1.4 KEY PERFORMANCE PARAMETERS

The expected performance of the 14m tri-band antenna system is provided hereunder.

Table 1-1: 14m S/X/K antenna key performance parameters

SYSTEM PERFORMANCE	
Tracking	Program Track Program Track with PCS Step-Track S/X/K-band Monopulse Track and Autotrack
Frequency band	K-band (Rx & Trk: 25.5 to 27.0 GHz) X-band (Rx & Trk: 8.025 to 8.5 GHz; Tx: 7.145 to 7.250 GHz) S-band (Rx & Trk: 2.200 to 2.300 GHz; Tx: 2.025 to 2.120 GHz)
Antenna gain	68.7 dB @ 25.5 GHz @ LNA input 59.6 dB @ 8.025 GHz @ LNA input 57.8 dB @ 7.145 GHz @ HPA output 47.7 dB @ 2.200 GHz @ LNA input 47.4 dB @ 2.025 GHz @ HPA output
Antenna G/T @ 5° elevation	43.7 dB/K @ 25.5 GHz 38.4 dB/K @ 8.025 GHz 26.8 dB/K @ 2.200 GHz
EIRP	80.8 dBW @ 7.145 GHz 67.4 dBW @ 2.025 GHz
Radiation pattern	Complies with ITU-R S.465-5
Angular accuracy (1σ)	Tracking, no wind (S/X/K): 0.036°/0.015°/0.007° Tracking, op. limit (S/X/K): 0.036°/0.015°/0.007° Pointing with PCS, no wind (all bands): 0.006° Pointing with PCS, op. limit (all bands): 0.009° Pointing, no wind (all bands): 0.035° Pointing, op. limit (all bands): 0.035°
ANTENNA OPTICS	
Configuration	Ring focus optics
Reflector diameter	14.0m
Reflector surface accuracy	< 0.25mm RMS
3dB beamwidth	0.056° @ 27.0 GHz 0.172° @ 8.500 GHz 0.652° @ 2.300 GHz
HUB CHARACTERISTICS	
Available space for housing RF equipment	Approx. 2 m x 2 m x 1.7 m (20RU in 19" racks)

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SYSTEM PERFORMANCE	
Environment	Closed sealed space Temperature controlled
AXIS DESIGN	
Full motion AZ1/AZ2/EL mount	Without keyhole, for LEO operation
Dual backlash compensated drives	All axes
Mechanical locking mechanism	On AZ1 with discrete positions
AZIMUTH 1	
Operational travel range	360°
Maximum rate	4.0 °/s
AZIMUTH 2	
Operational travel range	±270°
Maximum rate	8.0 °/s
ELEVATION	
Operational travel range	-1° to 95° (w.r.t. horizon in nominal AZ2 position)
Maximum rate	1.5 °/s
ENVIRONMENTAL CONDITIONS	
Temperature	Operational: -20 – +40°C Survival: -30 – +50°C
Humidity	0 – 100 % including condensation
Wind	Operational: Mean 100km/h, Gust 120km/h Survival: Peak 200km/h
Ice	Operational: 5mm except reflectors Survival: 10mm
Snow	Operational: 30 mm/h Survival: 30 mm/h
Rain	Operational: 20 mm/h Survival: 50 mm/h
Hail	Survival: up to ∅20mm

The expected performance of the 6.8m tri-band antenna system is provided hereunder.

Table 1-2: 6.8m S/X/K antenna key performance parameters

SYSTEM PERFORMANCE	
Tracking	Program Track Step-Track S/X/K-band Monopulse Track and Autotrack
Frequency band	K-band (Rx & Trk: 25.5 to 27.0 GHz) X-band (Rx & Trk: 8.025 to 8.5 GHz; Tx: 7.145 to 7.250 GHz) S-band (Rx & Trk: 2.200 to 2.300 GHz; Tx: 2.025 to 2.120 GHz)
Antenna gain	62.3 dB @ 25.5 GHz @ LNA input 53.3 dB @ 8.025 GHz @ LNA input 51.7 dB @ 7.145 GHz @ HPA output 41.5 dB @ 2.200 GHz @ LNA input 36.1 dB @ 2.025 GHz @ HPA output
Antenna G/T @ 5° elevation	37.4 dB/K @ 25.5 GHz 32.0 dB/K @ 8.025 GHz

System performance	
	20.3 dB/K @ 2.200 GHz
EIRP	74.6 dBW @ 7.145 GHz 56.1 dBW @ 2.025 GHz
Radiation pattern	Complies with ITU-R S.465-5
Angular accuracy (1σ)	Tracking, no wind (S/X/K): 0.100°/0.025°/0.011° Tracking, op. limit (S/X/K): 0.100°/0.026°/0.013° Pointing, no wind (S/X/K): 0.207°/0.054°/0.024° Pointing, op. limit (S/X/K): 0.213°/0.074°/0.056°
Antenna optics	
Configuration	Ring focus optics
Reflector diameter	6.8m
Reflector surface accuracy	< 0.5mm RMS
3dB beamwidth	0.116° @ 27.0 GHz 0.340° @ 8.5 GHz 1.296° @ 2.300 GHz
Hub characteristics	
Available space for housing RF equipment	~ 1.7 m x 1.4 m x 1.1 m (e.g. 30RU in 19" racks + 2 outdoor HPAs)
Environment	Closed sealed space Temperature controlled
Axis design	
Full motion elevation over azimuth over tilt mount	Without keyhole, for LEO operation
Dual backlash compensated drives	AZ and EL
Precision screw jack on tilt	
Tilt	
Operational travel range	± 7.5°
Azimuth	
Operational travel range	±270°
Maximum rate	15 °/s
Maximum acceleration	7.5°/s²
Elevation	
Operational travel range	-1 to 91°
Maximum rate	5 °/s
Maximum acceleration	7.5°/s²
Environmental conditions	
Temperature	Operational: -20 – +40°C Survival: -35 – +55°C
Humidity	0 – 100 % including condensation
Wind	Operational: Mean 80km/h, Gust 100km/h Drive limit: Mean 100km/h, Gust 130km/h Survival: Peak 200km/h
Ice	Operational: 5mm except reflectors Survival: 10mm
Snow	60mm/min
Rain	120mm/h
Air pressure	720 – 1084hPa
Altitude	≤ 1000m
Solar radiation	≤ 1120W/m²

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1.5 CONCLUSION

This study has allowed HITEC Luxembourg and Mirad Microwave to develop a 14m and a 6.8m S/X/K tri-band capable Earth Observation ground station antenna. The 14m design is based on a 14m S/K-band Earth observation antenna developed under a previous GSTP study performed jointly between HITEC Luxembourg and Mirad Microwave. The 6.8m design is based on a commercially available 6.8m S/X-band antenna from HITEC equipped with a dual-band feed from Mirad Microwave. The new antenna designs use the existing tri-band feed from Mirad Microwave which has already been realized and used for projects in the past.

The existing tri-band feed from Mirad has been integrated in both ground stations and a matching ring-focus optical layout has been designed for each antenna. Commercially available active components were selected for each of the 3 frequency bands and integrated into the antennas. In particular the placement of the HPAs in the antennas and the distribution of the active components in the available rack space was analyzed in detail.

Overall, the performance achieved for both antenna systems is very good. The project objectives could largely be achieved with only one non-compliance: the achieved G/T of 43.69 dB/K in K-band is slightly below the specification of 43.9 dB/K. All other major requirements, especially the G/T and EIRP requirements were fulfilled. Some partial compliances were obtained for secondary requirements.

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