IAC-19-B2/4/3/x51754

Lightweight Deployable X/Ku-Band Antenna for Land-Mobile Satellite Communication

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Abstract

Commercial parabolic ground antennas are widely used for first responders, disaster and crisis management, military operations, news teams and journalists, or for scientific expeditions. The key requirements that all these applications have in common are: the need for quick deployment, excellent transportability, and a very low weight. Therefore, the aim was to develop, manufacture and test a parabolic lightweight quickly deployable ground antenna for satellite communications. The design of the antenna should be in such a way that a small packing size is achieved but at the same time the accuracy of the reflective surface should not be affected to support data transmission in high frequency bands such as the X/Ku-band. Suitable materials, mechanisms for deployment, and a high frequency feeding system have been identified, selected and applied during the design process to achieve these goals. Especially carbon-fiber reinforced materials were used for the manufacturing in order to reduce the overall weight of the antenna to a weight of 13.7 kg of the prototype, with a potential for reduction down to 10 kg, at a reflector size of 1.2 m. The surface accuracy and its reproducibility were characterized via an optical 3D digitizer measurement system and were compared to the theoretical reflector shape. A compact antenna test range was used to carry out high frequency tests including the measurement of the antenna gain pattern. Finally, high frequency tests under typical operating conditions were performed to evaluate the performance proving the end-to-end connectivity of the new antenna.

Keywords: Deployable antenna, Ku-band, lightweight, satellite communication, man pack, VSAT.

1. Introduction

Deployable very small aperture terminals (VSAT) can be used where problems with wired communication arise, e.g. unstable networks due to overload or large distances. They can be used to reduce the load on cable-bound communication and expand communication networks quickly and cost-effectively. For example, the use of deployable VSAT antennas is predestined for any ground application where a low weight, an excellent transportability and a quick commissioning are the most important parameters.

This is very important for rescue operations in emergency and crisis situations, where communication between rescue units and the control center is important for coordinating assistance measures. Especially in the event of a missing and/or collapsed infrastructure - for example after an earthquake or flood disaster - the use of mobile communication equipment for the coordination of rescue forces is vital for the survival of the victims. Another terrestrial application of a small deployable antenna is in press and television coverage with voice, data and TV transmission. The flexible and location-independent use together with the fast commissioning are particularly advantageous properties. The small deployable antennas can also be used for data transmission from the exploration teams to the company headquarters when exploring and developing resources - for example when exploring oil and gas deposits. For environmental monitoring or earthquake warnings, automatic measuring stations in remote areas can transfer their data to remote control centers using a deployable antenna. In the field of military applications, small deployable antennas can be used for communication and data transfer between military units and to command posts.

The Ku and X frequency band for satellite communication is appropriate for the scenarios mentioned above. However, conventional VSAT antennas cannot be folded, as the antenna is usually a single-piece or sometimes a multi-piece segmented reflector. As a consequence, the reflector is difficult to transport due to several suitcases and is time consuming to bring into operational configuration. Due to these reasons, a new transportable deployable VSAT antenna has been developed by HPS GmbH that is capable to operate in the Ku- or X-band.

2. Antenna Design

HPS GmbH is responsible of the design, the manufacturing, the assembly and the tests of the X/Ku-band antenna reflector with type name KEAN (Figure 1, Table 1 and 2). The reflector is based on a deployment/stowing concept made of 12 foldable lightweight segments. In detail the antenna is composed of the following subassemblies:

- *Main reflector*: consists of carbon-fiber reinforced polymer (CFRP) segments forming the shape of the parabolic reflector. The 12 segments are mounted on the deployment mechanism, which in turn are fixed to the metal baseplate.
- *12 stringer*: The rectangular profiles are made of CFRP and serve as a stable structural support for the segments. The end-fittings are made of aluminum.
- *Tripod*: Three tripod legs whose telescopic tubes are made of CFRP are mounted to the gearbox. The gear end enables the reflector antenna to be adjusted in three axes via fine adjustment to precisely point it to the satellite.
- *Feed horn:* provided as customer furnished item by Cobham and the rotation unit, to adjust the polarization angle.
- *Antenna deployment mechanism:* Its functions are to deploy the 12 segments to form the parabolic reflector shape.

Figure 1. KEAN antenna on the mountain Kampenwand in Germany.

Table 1. KEAN reflector geometrical parameters.

Parameter	Value
F (Focal length)	270 mm
C (Clearance)	20 mm
Radius	600 mm

Table 2. KEAN antenna performance characteristics.

Antenna Performance Characteristics	
Mass of prototype (reflector + tripod)	< 13.7 kg (target for product: 10 kg)
Antenna diameter	1.2 m
Packing size	Diameter: 0.63 m Height: 0.80 m
Deployment of reflector	15 seconds
Bringing into service	17 min
Antenna	Gain 39.5 dBi at 11 GHz G/T 19 dB/K
Passive deployment: CFRP panels act as spring actuators	
Gear end with quick-change device: - Azimuth range 360° - Elevation range +90° to -30° - Polarization range 360°	

3. Testing

3.1 Surface Accuracy Measurement

The surface shape of the reflector antenna was measured with the GOM ATOS III Rev. 02 system [1] in order to later compare the three dimensional shape with the theoretical parabolic form. The measurement setup is shown in Figure 2. The ATOS sensor was equipped with two cameras and a MV320 optics. A measuring volume of 700 mm x 530 mm x 520 mm was used. The stickers for the measurement reference points were attached to the reflector surface, base plate, and the feed at random locations. These points are used by the ATOS scanner to join the individual scans together. In addition, the metallic and shiny parts were covered with a thin layer of matting powder by using an anti-glare spray. The powder helps to reduce light reflections at the surface. With this measurement first the deviation of the manufactured reflector from the parabolic shape was measured and second the repeatability of the surface shape after three times of folding and deployment.

Figure *2. Surface accuracy measurement with optical measurement system.*

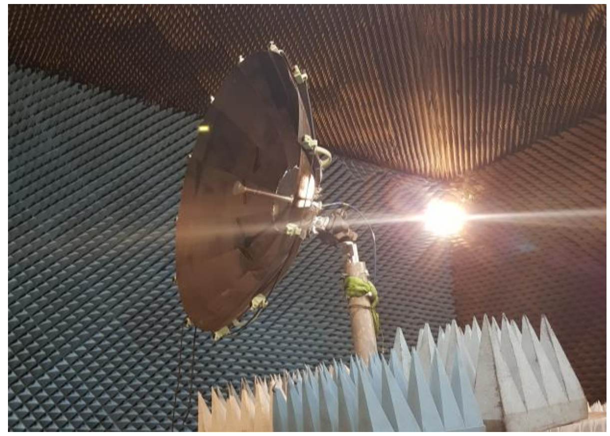

Figure 3. KEAN in compact test range chamber.

3.2 Compact Test Range Test

By means of a Compact Test Range the high frequency (HF) performance of the KEAN antenna was tested (Figure 3). The 14 m x 7 m x 6 m absorber chamber is completely lined with pyramidal foam and high performance absorbers. A 6-axis control unit with an accuracy of 0.03° ensures high-resolution measurements. The antenna is mounted on a rotor to easily change polarization. A foam-lined tower is used to minimize undesirable wave propagation effects and ensure accurate measurements.

The measurement results were assessed based on the EUTELSAT criteria [2] in the frequency range from 10.7 GHz to 14.5 GHz. The measurements were performed with the Antenna and Radar Cross-Section Measurement System (ARCS) from March Microwave Systems BV. A dual computer system enabled simultaneous acquisition and processing in a room adjacent to the compact test range chamber. A Rhode & Schwarz ZVA 40 was used to transmit and receive signals. Fast sweep time and high measurement speed with less than 3.5 µs per test point increase the performance of the system. An attenuation controller/switch driver automatically takes over the polarization of the transmitted signal and waveguides instead of coaxial cables minimize the loss of antenna reception signals.

3.3 End-to-End Field Test

In addition to the surface and the compact test range measurements, an end-to-end field trial has been performed over a transparent geostationary satellite. In order to validate the high frequency performance of the KEAN antenna under typical operational conditions, a bi-directional satellite connection with forward and return link has been established between the KEAN reflector and a larger hub station. The complete test setup is given in Table 3. The hub station was a 7.6 m anchor station equipped with a 400 W HPA resulting in an equivalent isotropically radiated power (EIRP) of approximately 85 dBW in saturation. The forward and return link has been established using two point-to-point DVB-S2X modems. The KEAN antenna was equipped with a 6 W block-upconverter (BUC), which results in a maximum EIRP of approximately 49.1 dBW.

Table 3. Setup of end-to-end field test.

Ground Parameters	**Value**
Ground location	11.63° E, 48.07° N
Azimuth / Elevation	234.4° / 19.4°
Satellite Parameters	**INTELSAT 35E**
Orbit position	34.5° W
Up- / Downlink frequency band	14 GHz / 11 GHz
G/T at Center-of-Coverage (CoC)	10 dB/K
Payload Gain	194 dB
EIRP sat. at CoC	55 dBW
Hub Station Parameter	**7.6 m Antenna**
EIRP sat.	85 dBW
G/T at 11.5 GHz	37 dB/K

4. Test Results and Discussion

4.1 Surface Accuracy Measurement

The measurement data were evaluated with the GOM Inspect software. The CAD-file of the theoretical parabolic shape can be imported and the deviations of the measured surface from the parabolic shape can be displayed using a color scale. The result of this comparison is shown in Figure 4. In average, a deviation of 4.5 mm was measured for the segment blades. The deviations are mostly at the long edge of the segment blades, which are not fixed to the stringer, indicated in yellow in Figure 4. In these regions, two CFRP segments overlap and the edges slightly lift off. In general, the surface geometry follows the parabolic shape from the base plate on the CFRP segments. The reflector was deployed three times and the surface shape was measured in order to compare the repeatability of the shape. The measurement result is shown in Figure 5. It can be seen that after deployment, the surface always returns to the same shape.

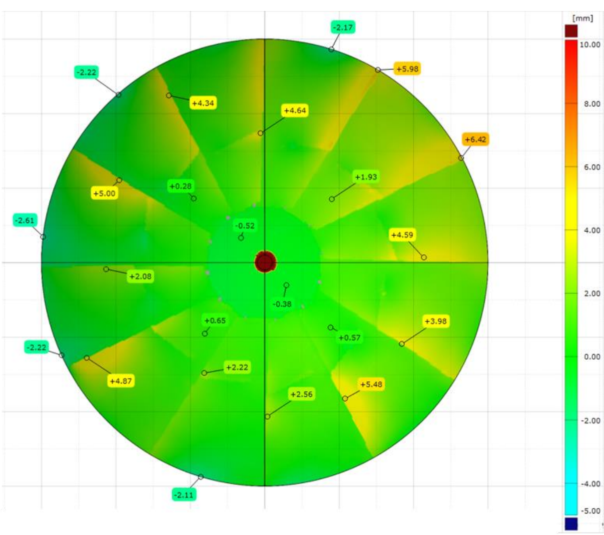

Figure 4. Comparison of measured and theoretical parabolic shape of KEAN reflector antenna.

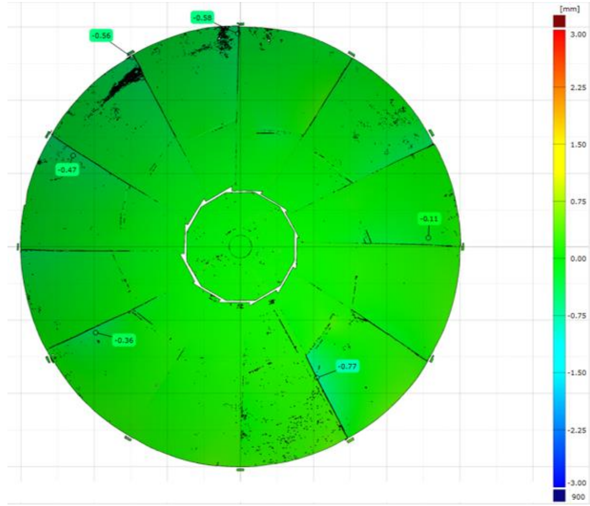

Figure 5. Comparison of surface shape after three times of deployment of the reflector.

4.2 Compact Test Range Test

The KEAN antenna feed was oriented in the compact test range chamber parallel to the ground. In this configuration, the gravity pulls the edges of the CFRP segments on the upper part of the KEAN reflector downwards. Thus, the reflector shape deviates from the parabolic shape at the edges of the segment blades with an azimuthal periodicity. This influences the sidelobes near the main beam of the antenna HF performance. Figure 6 and Figure 7 show the pattern cut at the Rx frequency of 10.95 GHz and at the Tx frequency of 14.5 GHz. In the figures, the two side lobe boundaries specified by the Eutelsat standard [2] are shown with dashed lines. Due to the fact, that some of the segments took off from the stringer on the prototype; the sidelobes close to the main beam did not yet fulfill the Eutesat boundary criteria. With the identified improvements in design and processes, the compliance is expected.

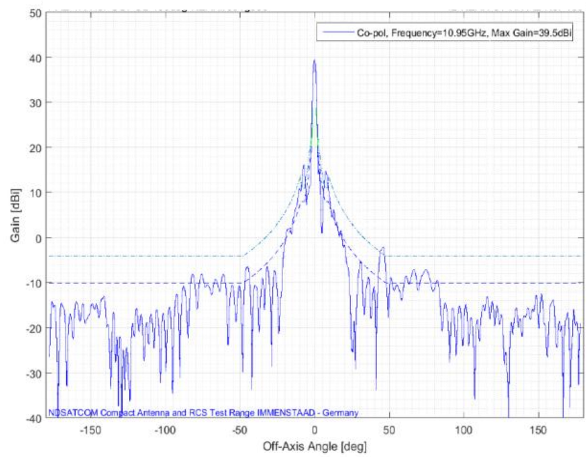

Figure 6. Rx at a frequency of 10.95 GHz (off-axis angle -150° to 150°).

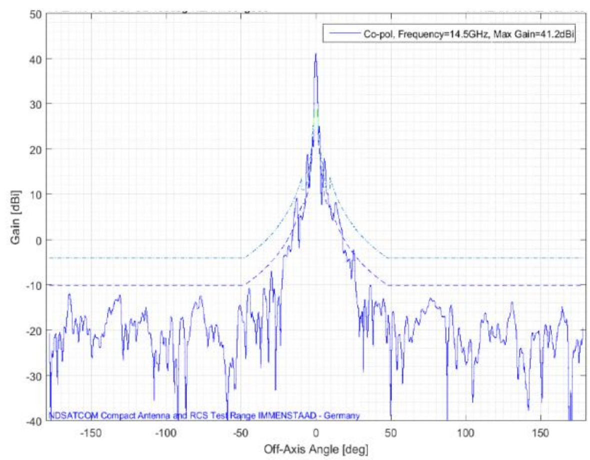

Figure 7. Tx at a frequency of 14.5 GHz (off-axis angle -150° to 150°).

4.3 End-to-End Field Test

The End-to-End field trials have been performed in August 2019 according to the setup provided in Table 3. During the tests, mainly clear-sky conditions with only a view clouds were present. An example link budget in Table 4 shows that the forward and return link can be closed with a total carrier-to-noise ratio of 9 dB and 3.5 dB, respectively.

Table 4. Link budget for end-to-end field test.

	Forward Link	**Return Link**
	Uplink	
Tx EIRP	48.9 dBW	33.6 dBW
Carrier Frequency	14.333 GHz	14.318 GHz
Total Path Loss	207.7 dB	207.7 dB
Effective G/T	9.2 dB/K	9.2 dB/K
C/N0	79 dB/Hz	63.7 dB/Hz
	Downlink	
Tx EIRP	31.3 dBW	16.1 dBW
Carrier Frequency	11.533 GHz	11.518 GHz
Total Path Loss	205.7 dB	205.7 dB
G/T	18.8 dB/K	37.3 dB/K
C/N0	73 dB/Hz	76.3 dB/Hz
	Total Link	
C/N0 total	72 dB/Hz	63.5 dB/Hz
Symbol Rate	2 MHz	1 MHz
C/N total	9 dB	3.5 dB

Assuming a conventional DVB-S2X modem providing 8 PSK, forward error correction (FEC) 25/36 and QPSK with FEC 11/20, these values are sufficiently high to achieve a data rate of 4.2 Mbit/s and 1.1 Mbit/s in the forward and return link, respectively.

Please note that the achieved data rates strongly depend on the power of the space segment. Future High-Throughput-Satellites are expected to provide much higher gains in terms of EIRP and G/T and are, therefore, more suitable to operate small 1.2m VSATs. In addition, the Output-Backoff (OBO) of about 15 dB of the KEAN antenna was relatively high (limit provided by the satellite provider). Since the return link is limited by the uplink, the achievable data rate can be further increased by reducing the OBO appropriately.

5. **Conclusions**

The lightweight deployable X/Ku-Band antenna KEAN for transportable satellite communication has been developed, manufactured and tested by HPS GmbH. The main characteristic of the KEAN antenna are:

- Transportability is achieved by a small package size in which the antenna is folded and a low weight by usage of light-weight materials such as CFRP for the ribs and segment blades for the reflective surface;
- A fast set-up for operations and to establish a satellite data-link was achieved with the passive

deployment mechanism of the CFRP blades that act as spring actuator.

- A consistently stable and reliable data transmission was proven by compact test range and end-to-end field tests. By a slightly adjustment of the design in such a way that the surface geometry does not deviate under gravity and possible windy environment, the antenna performance can be further increased.

The above characteristics make the KEAN antenna suitable for personnel that require a rapidly deployable antenna for high-bandwidth satellite communications.

Acknowledgements
This development/project was supported by the German Aerospace Center (DLR) with funds from the Federal Ministry for Economic Affairs and Energy according to a decision of the German Federal Parliament.

References

[1] Atos Triple Scan User Manual – Hardware, ATOS II and III Triple Scan, 2012.
[2] Earth Station Minimum Technical and Operational Requirements. Standard M, EESS 502, Iss.15, Rev.2