A Multibeam Antenna for Data Relays for the German Communications Satellite Heinrich-Hertz

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***Abstract*— This paper presents a concept of a novel Ka-band receiving multibeam antenna that can be used for high-rate data relays between a GEO satellite and several LEO satellites. The antenna is a payload candidate for the German communications satellite *Heinrich-Hertz* that is intended to be launched in 2014. First numerical results assessing the radiation characteristics and performance of the proposed antenna are given.**

I. Introduction

With the increasing development of communication technologies for applications in space during recent years, there has been growing interest in building a German national geostationary telecommunications satellite. Therefore, in early 2009 the conceptual planning phases for the so-called "Heinrich-Hertz Satellite" (H2Sat) were initiated by the Space Agency of the German Aerospace Center (DLR). The scientific and technical goals of H2Sat, which is intended to be launched by mid of 2014, are in particular to provide a unique platform for the in-orbit verification of novel and innovative payload technologies putting a strong focus on systems designed for operation in Ka-band.

Being a geostationary (GEO) satellite, H2Sat offers the opportunity to serve as a data relay station for low-earth-orbit (LEO) satellites. In recent years, the amount of data acquired by single LEO satellites (e.g. during earth observation) has grown tremendously. Therefore, the relatively short span of time, during which a given earth station can maintain contact to a LEO satellite to download all the gathered data represents an increasingly serious bottleneck. One possibility to circumvent or at least alleviate this is to realize higher downlink data rates. However, in general that affords a higher effective isotropic radiated power (EIRP) of the LEO transmitting antenna and/or a higher gain of the earth station receiving antenna, both cases of which being typically strong cost drivers. Another costly approach often chosen is to increase the access time to LEO satellites by employing a world wide network of earth stations. In contrast to that, GEO data relays represent an elegant way to realize long contact times to LEO satellites based on only one earth station, since any LEO satellite will be visible for the GEO satellite for at least 50% of its orbital period.

This can be illustrated by a small example. For that purpose, we consider a typical LEO earth observation satellite orbiting the earth at an altitude of ~800 km with polar inclination. Such an orbit may have about a period time of 100 min resulting in the satellite circling the earth about 14 times per day. On average, the satellite would have about 7 direct contacts to a single earth station (e.g. DLR site Neustrelitz) each lasting ~10 min. In contrast to that, such a LEO satellite would be visible from a GEO satellite during each orbit period for about 70% of the orbit time resulting in a GEO data relay contact time per day of ~980 min in comparison to the ~70 min in the case of direct contacts to a single ground station. That factor of 14 higher GEO data relay contact time can be utilized to increase the transmitted data throughput and/or to reduce the data rate requirements depending on the application specific needs. For many state of art earth observation satellites, a data rate of some tens of Mbit/s provides already a sufficient data download capacity, if a GEO data relay is being employed instead of a direct link to a given single ground station.

Moreover, even simultaneous data link communication from multiple LEO satellites to one GEO becomes feasible without a complex implementation of various tracking single reflectors, if a suited multibeam antenna is used for receiving the signals.

To demonstrate and utilize the advantageous potential of GEO data relays on-orbit, we propose a novel Ka-band multibeam antenna as payload component for H2Sat, which is capable of serving as the key element of multiple high bit-rate GEO data relays[1].

II. Multibeam Antenna

For high data rate communication between GEO and LEO satellite antennas with high gain are required. Instead of equipping many LEO satellites with large antennas it is advantageous to have an antenna with higher gain on the GEO side. When considering link budget calculations for a carrier

[1] The multibeam antenna presented here is a conceptually modified variant of the so-called "GeReLEO" multibeam antenna that is being developed within the project "GEO data relays for low earth orbit satellites – GeReLEO" funded by the DLR Space Agency.

frequency of 26 GHz it turns out that it is enough to have a LEO antenna gain of about 37 dBi (EIRP 54 dBW) and a GEO antenna gain of approximately 42 dBi (G/T 15.1 dBi/K) for the data transfer between the LEO and the GEO antennas at a rate of 30 Mbit/s. Therefore, a LEO antenna composed of a simple mechanically steered reflector with a diameter of about 40 cm would be sufficient. For obtaining multibeam capability on the GEO side, an electronically steerable antenna is attractive.

In general there are two basic architectures of electronically steerable antennas with multibeam capability: A direct radiating array (DRA) and an array of feeds positioned close to the focal plane of a reflector. Obtaining the required high gain with the first solution would lead to a very high number of radiating elements that would be prohibitive due to the enormous complexity of a control logic. Some simplified solutions to DRA for satellite communications have already been presented, e. g. [1]. However, they are limited to very low scan volume and few beams. The second solution is more suitable, as high gain is obtained through the aperture of the reflector allowing to use an array of feeds having considerably fewer elements than the first option.

There are many types of curved reflector antennas. They can be front-fed or use an additional subreflector to place the antenna feed at the vertex of the main reflector [2]. For the application presented in this paper a concept with classical front-fed curved reflector would lead to an architecture, in which the array of feeds is located outside the satellite, heavily exposed to high temperature differences that might roughly range from -170°C to +120°C. Also offset feed configuration that may allow to partially hide the array of feeds inside the satellite can not be used because of unfavourable scanning capabilities. Therefore, to protect the active components integrated in the array, we propose a dual-reflector arrangement (see Fig. 1). The array of feeds is then mounted at the base of a parabolic main reflector and the top layer of the array is aligned with the satellite surface partially protecting the underlying layers with active components from the harsh environment.

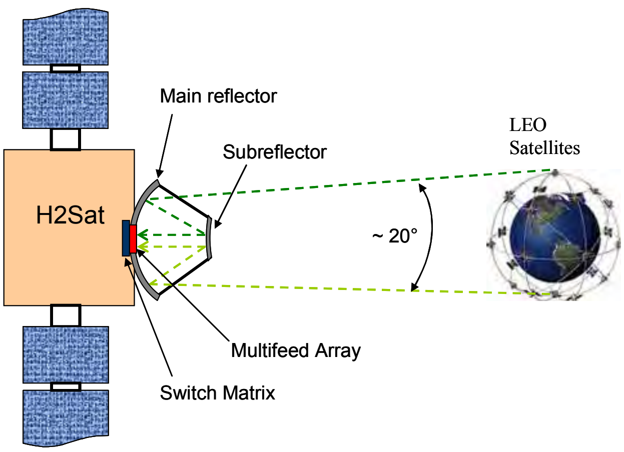

Fig. 1 Dual-reflector Cassegrain arrangement of the multibeam antenna

A. Multifeed Array

As radiating elements circularly polarized patches operating at around 26 GHz will be used. Each beam will be received with the help of a 2x2 sub-array with fixed beamforming network and a distance between elements of about 0.5λ. Sequential rotation technique of sub-array elements will be employed to improve the purity of circular polarization and the symmetry of the feeder radiation pattern. Beams coming from different directions will be received by different 2x2 sub-arrays. The LEO satellites will be tracked by switching between the 2x2 sub-arrays corresponding to their beam directions.

Behind each 2x2 sub-array a low noise amplifier (LNA) is integrated in the multifeed array antenna structure. The LNAs will be individually controlled and kept turned off for the time when the corresponding sub-array does not receive any data from a LEO satellite.

A schematic view of the proposed antenna is shown in Fig. 2.

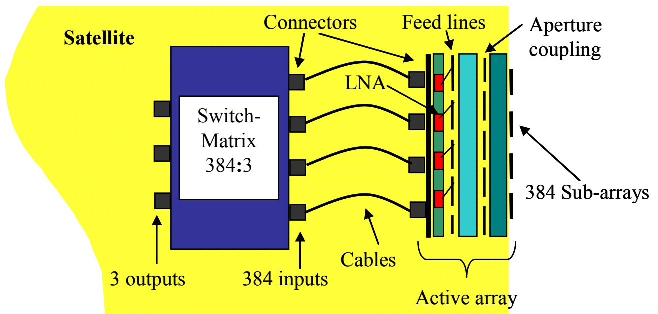

Fig. 2 Schematic view of the proposed multibeam antenna (reflectors are not shown)

The array will have hexagonal or octagonal shape and will presumably consist of 384 sub-arrays of 2x2 elements arranged on a hexagonal grid.

B. Switch matrix

Out of this high number of possible beams signals from up to 3 sub-arrays will be simultaneously received, routed to transponders and sent to an earth station with a feeder link. Therefore, a switch matrix that is capable of switching signals from any of 384 sub-arrays to any of the 3 outputs is required.

Due to high complexity of such a matrix it is very important to use components and technologies that have low attenuation of the useful signals and low energy consumption. The latter is not only important because of limited power generation capability of the satellite but also due to power dissipation. The heat generated inside the satellite must be dissipated outside of it and the heat pipes used for that purpose increase significantly the weight of the satellite. The switch matrix will be implemented in Micro-Electro-Mechanical Systems (MEMS) technology, since they allow an implementation with low loss and power consumption.

C. Reflectors

The maximal possible diameter of the main reflector is limited to 1.2 m for the Heinrich-Hertz satellite. As the biggest part of the multibeam antenna the reflector system is also its heaviest component. Because one of the design goals is to keep the weight of the multibeam antenna as low as possible, it was decided not to use aluminium but carbon fibre-reinforced plastic (CFRP) coated with a thin metallic layer. Although CFRP is relatively new in the satellite applications, it was already employed as a material for the slotted waveguide radiator for the German radar satellite TerraSAR-X [3].

III. Development and Numerical Results

Preliminary calculations and simulations of the antenna have been performed to assess its radiation characteristics.

As a first task, one has to define the global field of view that the antenna should cover. This decision for sure leads to a trade-off between the maximum altitude of LEO orbits to be covered in their full expansion on the one hand and the size and complexity of the array on the other. As already mentioned above, each 2x2 sub-array should cover a certain area of the antennas global field of view dependent on its position within the array. Due to the fact, that parabolic antennas only focus perfectly paraxially incoming radiation, the gain achieved at different antenna elements degrades with raising distance of the elements from the antenna axis (see Fig. 4). This has to be considered additionally. A statistic investigation that we performed about the distribution of LEO orbits shows that a ±10° global field of view suffices to cover orbits up to ~950 km altitude in their full range, which includes more than 80% of all existing LEO orbits. For sure higher orbits will still be accessible at a high fraction of their orbiting time.

Referring to this result we fixed the global field of view to ±10°. Subsequently, the size of the array has to be defined. This parameter is influenced by the choice of the F/D of the main reflector and the shape and distance of the subreflector. Moreover, we decided to install the array at the base of the main reflector in the current version of our design, so as to allow the integration of the active components inside the satellite. Simulations showed, that a main reflector diameter of 1.2 m with an F/D = 0.75 and a flat subreflector at 45 cm distance leads to an acceptable array diameter of about 32 cm. The corresponding area of the array can be filled with 384 sub-arrays in a way, that allows to cover the whole global field of view of ±10° with sufficiently high gain and spatial resolution. The chosen set of antenna design parameters results in a coverage area of one single spot of about 1°.

This preliminary antenna setup was simulated using *GRASP* [4] and *FEKO* [5]. The geometry using the parameters explained above is shown schematically in Fig. 3. A circular hole with 17 cm of radius was cut in the main reflector to allow the installation of the array.

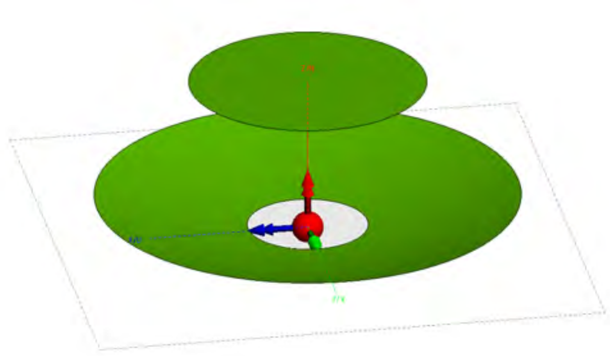

Fig. 3 Dual-reflector antenna modelled in FEKO. The red sphere indicates the position of the field source

The simulations in *FEKO* were carried out for a frequency of 26 GHz employing the multi-level fast multipole method (MLFMM). The dual-reflector structure has been discretized with a mesh composed of triangular elements with edge sizes of $\lambda/8$, where λ is the wavelength in free space. This resulted in a grid composed of nearly 2.1 million triangles.

The complete feeder with 384 elements could not be modelled with the available computational resources. Therefore, a 2x2 array composed of sequentially rotated circularly polarized patches has been simulated separately in *Ansoft HFSS* [6]. The far-fields produced by such an array have been imported in *FEKO* and used as field source to start the computations. This is indicated by the red sphere in Fig. 3. Thus, mutual coupling between the elements of this 2x2 array has been taken into account.

A comparative simulation has also been performed with *GRASP* using physical optics (PO) as method of analysis. Eleven feed array elements along one radial line of the array have been placed, each using the 2x2 pre-calculated pattern from *Ansoft HFSS*.

Fig. 4 shows the assessment of the scanning capabilities of the dual-reflector antenna depicted in Fig. 3. The simulated patterns were computed with *FEKO* and correspond to different scanning angles varying the position of a 2x2 array from the symmetry axis up to a distance d = 160 mm. As the antenna is rotational symmetric the region between 0° and 10° shows the corresponding values.

For the purpose of validation, a comparison between the results obtained with *FEKO* and *GRASP* for three scanning angles is shown in Fig. 5. Excellent agreement has been obtained at least down to the third sidelobes. The discrepances in the peak gain of each curve are lower than 0.1 dB.

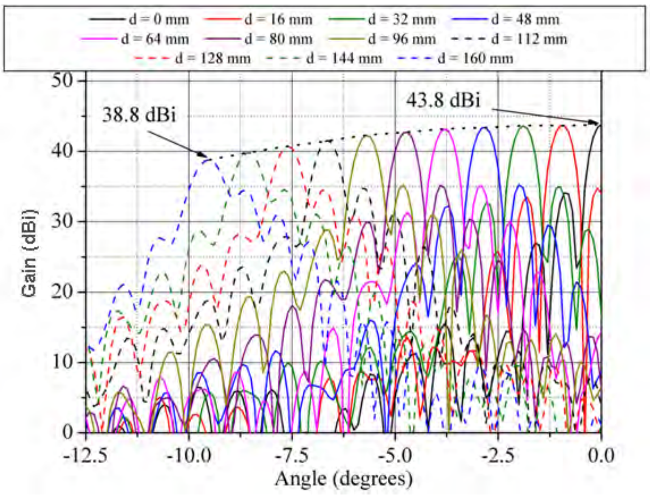

Fig. 4 Scanning capabilities of the dual-reflector antenna

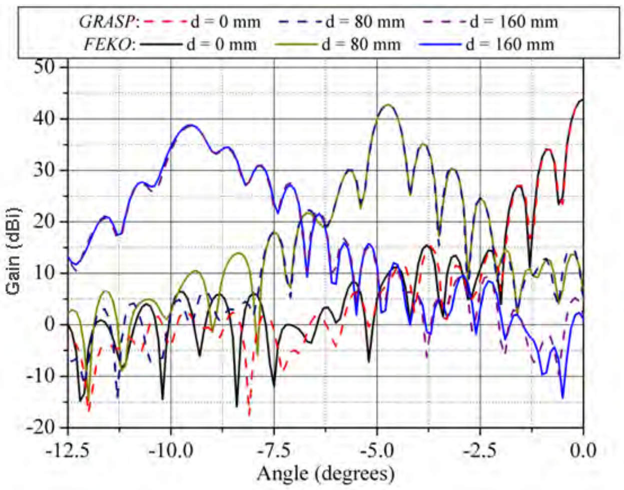

Fig. 5 Comparison between the results computed with *FEKO* and *GRASP*.

The optimization of the antenna system has not been finalized yet, so that further improvements on the performance are still expected. The gain varies roughly between ~38 dBi and ~44 dBi and therefore the rate of around 30 Mbit/s for communication with the LEO satellites can be achieved. Additional simulations that include the coupling between the 2x2 sub-arrays as well as final optimization of the whole antenna are still to be performed.

IV. Conclusions

In this paper a concept of a multibeam antenna for high-rate data relays was presented as a payload proposal for the German *Heinrich-Hertz* small GEO communications satellite. The antenna architecture and its most important parts were described. Preliminary numerical results showed that the proposed antenna is capable of serving as high-rate data relays between a GEO satellite and several LEO satellites. Excellent agreement between two commercial software programs based on different numerical methods was observed. Final optimization of antenna parameters has not been performed yet, so that further improvements of antenna performance are expected.

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