Lens-based Ka-band antenna system using planar feed

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***Abstract*—This paper presents a simple, low-cost and compact mobile ground terminal antenna for Ka-band satellite communications that operates in the downlink band (19.7-20.2 GHz). The antenna is composed of a shaped dielectric lens which tilts in front of a planar feed to direct the beam. The planar feed is a circularly polarized patch antenna placed inside a cavity. The lens allows a mechanical beam steering from 0° to 57° in relation to zenith with a scan loss of 4.5 dB. In order to show the potential of a planar antenna as a feeder for this application, the proposed system is compared with a previous solution composed of the same dielectric lens and a horn antenna as feeder.**

Index Terms—Satellite communications, Ka-band, mechanical beam-steering, dielectric lens, planar feed.

I. INTRODUCTION

Ka-band satellite technology has boosted the interest in satellite-on-the-move (SOTM) applications [1]. The ground terminal antenna has to steer the beam in order to keep up the link with the satellite. Steerable antenna systems are commonly classified into three main categories: electronic [2], [3], mechanic [4]-[6] and hybrid [7] beam scanning solutions. Electronically steered systems allow very fast change of the pointing angle and can be compact in terms of height. However, these systems have a complex feeding network which increases the terminal cost. Thus, mechanical beam steering solutions are commonly chosen for ground-segment SOTM due to their low cost. Still, these systems are quite bulky and research efforts focus on reducing their size. This way, Ka-band systems could be targeted not only to commercial moving platforms (like high-speed trains, buses or airplanes) but also to personal use (like small boats or all-terrain vehicles).

This context motivates the main goal of this work, which consists on reducing the size of an antenna system working in downlink Ka-band (19.7–20.2 GHz) previously developed by some of the authors [5]. In brief, the system presented in [5] is based on mechanical steering and it consists of a stationary circularly-polarized feed that illuminates a shaped dielectric lens that tilts in order to provide the scan of the beam. The stationary feed consists of a horn with a 45°-slant aperture, and its phase center is coincident with the lens focal point in order to reach the best performance and also to obtain a wide beam tilt angle. In this contribution, we aim at maintaining the basic principle of operation from the previous solution but replacing the horn by a planar antenna in order to reduce the size of the overall system. The performance of both systems is here compared basing on full-wave simulations results. This paper is organized as follows. The comparison between both feed antennas is presented in Section II. The performance of the complete antenna system is analyzed in Section III. Conclusions and future work are drawn in Section IV.

II. PLANAR ANTENNA VS HORN FEED SYSTEMS

The horn antenna used in the previous solution [5] is composed of two parts: the fixed component is a circular waveguide and the movable one is a 45°-slant aperture horn. The slanted aperture was adopted to help the lens to increase its scan range. The maximum height of the previous feed is 45 mm. The planar antenna that has been developed to replace the horn is shown in Fig. 1 and consists of a circular cavity with three thin layers of dielectric that accommodate two circular patches and four circular capacitive disks that are connected to the microstrip lines by pins. In order to achieve good quality circular polarization, these four pins are fed in sequential rotation (each of them having equal voltage and phase differences of 0°, 90°, 180° and 270°, respectively). Note that a feeding network should be designed in order to divide the power and to provide these phase shifts, however in this contribution we will assume ideal ports at each pin. The height of the dielectric layers placed inside the cavity is 0.127 mm and its permittivity is $\varepsilon = 2.33$. The diameters of the upper and lower patches are 5 mm and 5.75 mm, respectively. The diameter of the capacitive disks is 0.5 mm (other relevant dimensions are detailed in Fig. 1). The greatest advantage of the planar feed is its compact size. The height of the feed is reduced in more than 90% by using the proposed planar antenna instead of the horn (see Fig. 2).

As previously mentioned, the phase center position of the feed should be always coincident with the lens focal point in order to have the best focusing performance (i. e., highest gain and directivity). The phase center positions associated to each feed over the downlink Ka-band are shown in Fig. 2. The phase center position at 20 GHz is highlighted because it will be used in the simulations with the lens. It can be seen that the phase center position of the planar feed is more stable in this frequency band, thus becoming the more advantageous candidate. This figure also helps to point out the difference between both antennas: the maximum gain of the planar feed will be along z-axis but in the horn case it will be tilted 10° due to its 45°-slant aperture. Moreover, due to its aperture asymmetry, the horn must rotate synchronously with the lens to achieve a full scan in azimuth. This increases the complexity and the cost of the horn feed system in comparison to the planar feed system that remains fixed. As it is well known, there is always a compromise between performance, simplicity and cost. Here we aim at clarifying these relevant aspects and show a fair comparison in order to demonstrate that planar feeds can be potentially good candidates to feed the lens in this type of application.

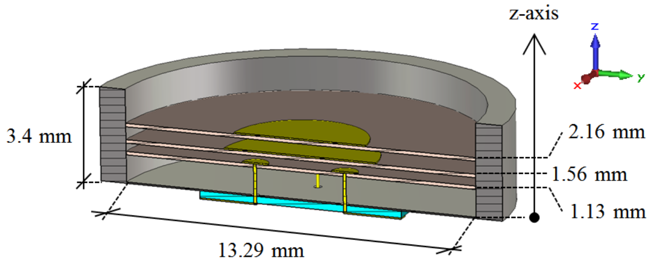

Fig. 1 – Cross-section view of the planar feed antenna: a circular polarized cavity-backed stacked-patch antenna with four-port capacitive feeding.

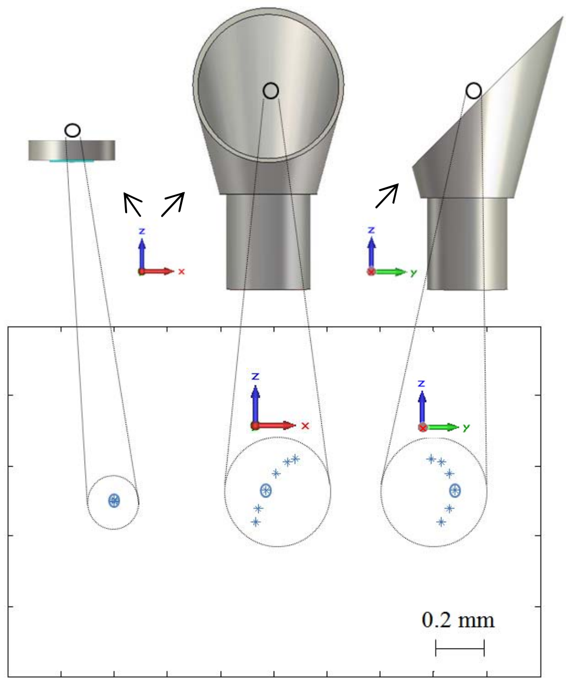

Fig. 2 – Comparison between the spatial phase center position of the planar feed and the horn at downlink Ka-band (19.7 to 20.2 GHz). The value obtained for 20GHz is surrounded by a circle.

As we are dealing with a multi-port device, its matching can be analyzed by considering its active S_{11} parameter [8], which is shown in Fig. 3 over the downlink Ka-band. This figure also shows the matching of the horn-feed system. We can see that both systems provide reflection coefficients below -10 dB in the whole band. The realized gain of both systems is presented in Fig. 4, and as it could be expected [8], the gain is greater in the case of the horn and its value is also more uniform over the frequency band of interest.

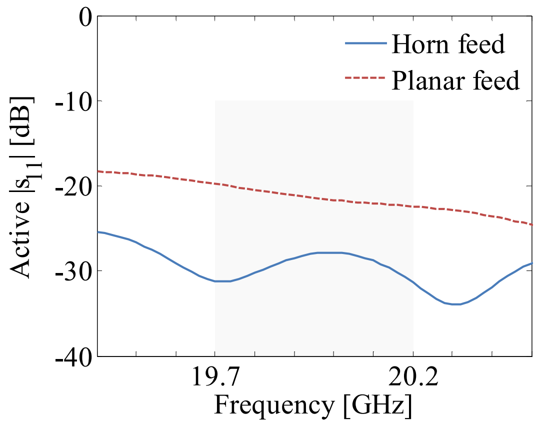

Fig. 3 – Matching of the feed in downlink Ka-band. Comparison between the planar antenna and the horn.

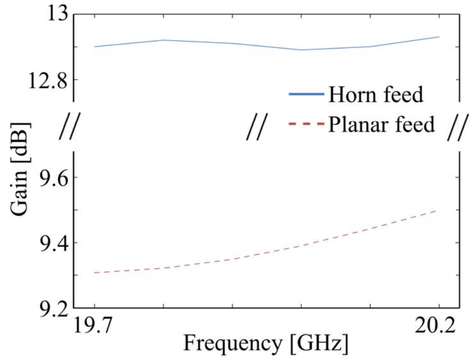

Fig. 4 – Realized gain comparison between the planar feed and the horn.

III. Antenna System

The dielectric lens is intended to increase the directivity from the feed and also to provide the beam steering. The lens was designed in [6] in order to widen as much as possible the scanning angle interval and to maximize the portion of the output lens surface that is able to collimate the feed radiation. As explained in [6], this lens can be illuminated by a feed that radiates along the z-axis and achieve a scan range from -45° to 45° with a stable scan loss. The maximum lens diameter is 87.5 mm and the height is 60 mm. The distance between the bottom surface of the lens and its focal point is 15 mm. The lens material is Polyethylene with relative permittivity and loss tangent values of $\varepsilon = 2.35$ and $\tan(\delta) = 0.0004$.

The full-wave results of the complete system have been obtained at 20 GHz [9] by tilting the lens from 0º < α < 60º, as it is depicted in Fig. 5 and it was also done with the horn in [5]. As already explained above, the lens focal point is placed in the phase center position at 20 GHz in both cases. The obtained radiation patterns are shown in Fig. 6 for circular polarization. As explained in the introduction, the beam tilt angle is almost coincident with the corresponding lens tilt angle and the beam shape is not much deformed with the lens tilt (see Fig. 6). The maximum gain in the planar feed's case is obtained for the beam tilt angle θ = 0º and this value decreases when the lens is tilted (see Fig. 7). This is coherent with the fact that maximum illumination from the planar feed is produced when the lens is placed along the direction of its maximum directivity. The gain scan loss is 4.5 dB at θ = 57º. It is important to remember that in the horn's case the feed radiation is tilted 10º thanks to the asymmetry of the structure [5]. Despite the fact that the horn is more directive than the planar feed, the whole system provides more directivity when the latter one is considered. This can be explained by considering that the lens was not optimized for any specific feed, but considering an ideal low-directive point source [6]. Thus, the planar feed illuminates a bigger portion of the lens' bottom surface (see Fig. 5), producing higher directivity. Fig. 7 also shows that the planar feed also provides greater scan loss and also a less stable gain than in the horn's case. This happens because over the lens scan range, the spill over in the horn's case is lower than in the planar feed's case (see Fig. 5). However both systems provide approximately the same gain at θ = 57º. It is important to highlight these differences in order to decide between both systems, taking into account the requirements of the application.

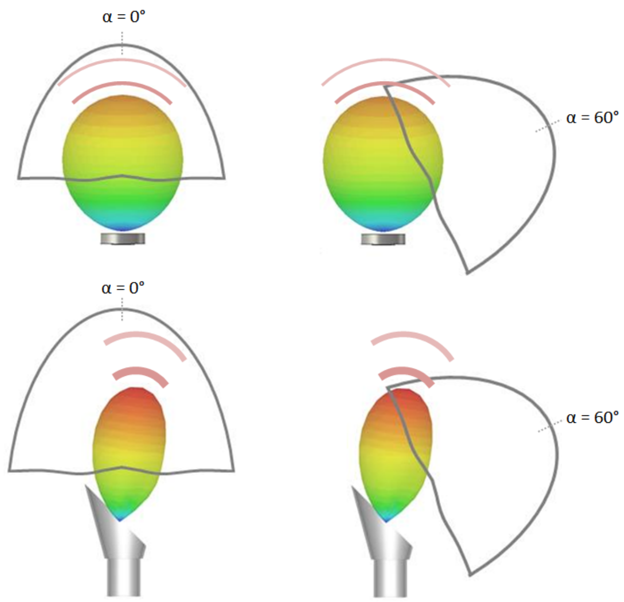

Fig. 5 – Comparison of both antenna systems.

IV. CONCLUSIONS

The paper presents a simple, low-cost and compact lens antenna system using a planar feed. The antenna system is compared with a previous one based on the same lens but using a horn as a feeder. The results show that the planar antennas are good alternative solutions to use as feeders, especially in cases where compactness and gain are important requirements. Being a proof of concept, the study was done only at downlink Ka-band. However the authors are currently developing an improved lens based antenna system using a more sophisticated planar feed able to work at both downlink and uplink Ka-bands.

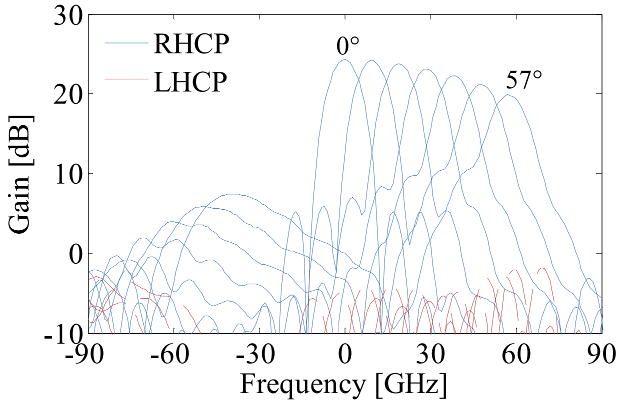

Fig. 6 – Simulated co- and cross-polar radiation pattern of the complete antenna system (planar feed and lens) at 20 GHz (0º < α < 60º).

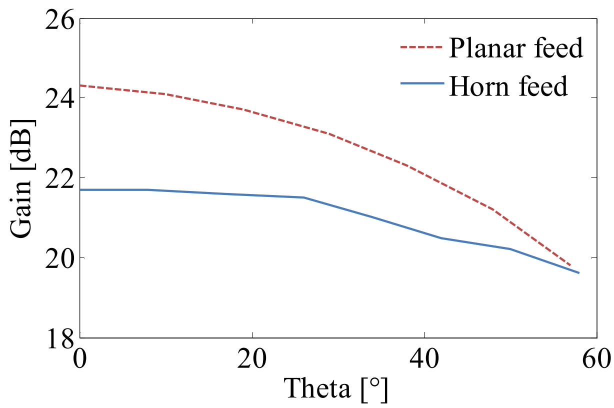

Fig. 7 - Comparison of the simulated results of the antenna using both feed systems at 20 GHz.

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