A Gap Waveguide-Based 2×2 Circularly-polarized Monopulse Antenna Array

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***Abstract*—This paper presents a circular-polarized gap-waveguide-based compact monopulse array antenna for millimeter-wave tracking applications at Ka-band (29 to 31 GHz). The gap waveguide planar monopulse comparator network is integrated in a single layer with a 2×2 corporate-fed network combining ridge gap and groove gap waveguides. Radiating cavities consist of cubes with chamfered corners. Preliminary results show a bandwidth of 2 GHz with input reflection coefficients better than -20 dB for both ports of the antenna. In addition, the isolation between ports is greater than 50 dB. The design allows for scalability to build higher gain arrays from the antenna presented in this communication.**

***Index Terms*—antennas, array, circular polarization, gap waveguide technology, monopulse antenna.**

I. INTRODUCTION

Antennas for satellite communications on the move (SOTM) are currently of great interest. Antennas mounted on a moving platform provides a controlled heading that enables a geosynchronous satellite to communicate with the ground [1]. An aspect that it is important to study is what happens to the communication of SOTM antennas in the event of changes in elevation or even in the event of unexpected vibrations. In these cases in which the antenna could lose communication, a monopulse tracking method would be effective for antenna pointing control on the vehicle.

In the literature, countless examples of monopulse antennas can be found. Reflector antennas, for example, are good candidates, thanks to their ease of design and good performance [2]-[3]. However, bulky structures are usually not suitable for implementation in modern communications systems. Alternatively, substrate-based antennas can be a low-profile and low-cost solution [4]-[5]. However, the need for low-loss substrates, and a narrow bandwidth are some of the drawbacks of this SIW or microstrip antennas. A trade-off solution between these two alternatives are full-metal planar array antennas, which can provide high-gain performance together with compact and low-profile structure for monopulse applications. Of course in this case they will always be bulkier structures than substrate-based antennas but less than reflectors, so they are intermediate solutions.

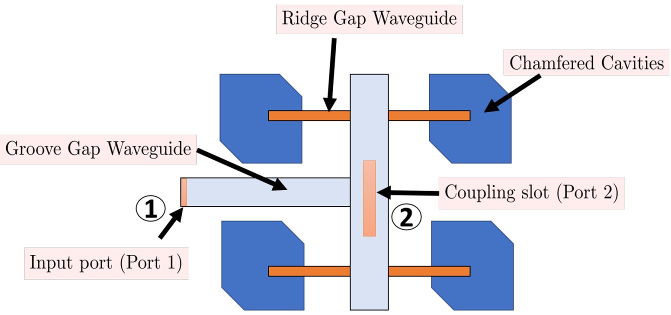


Fig. 1. Schematic of the feeding network and radiating elements of the unit cell.

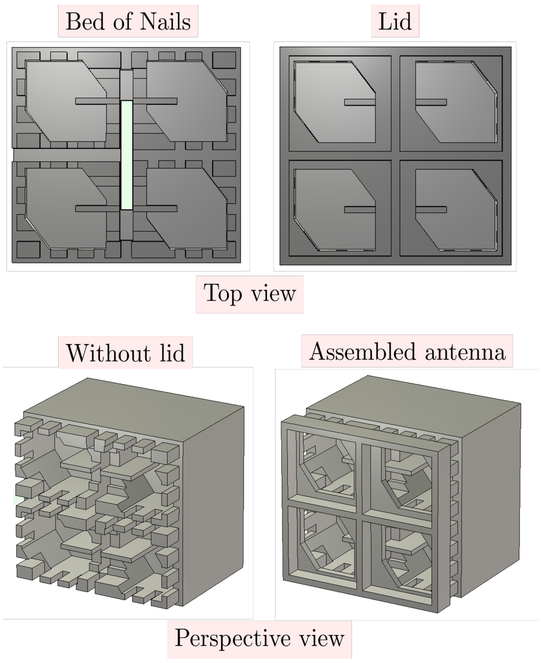
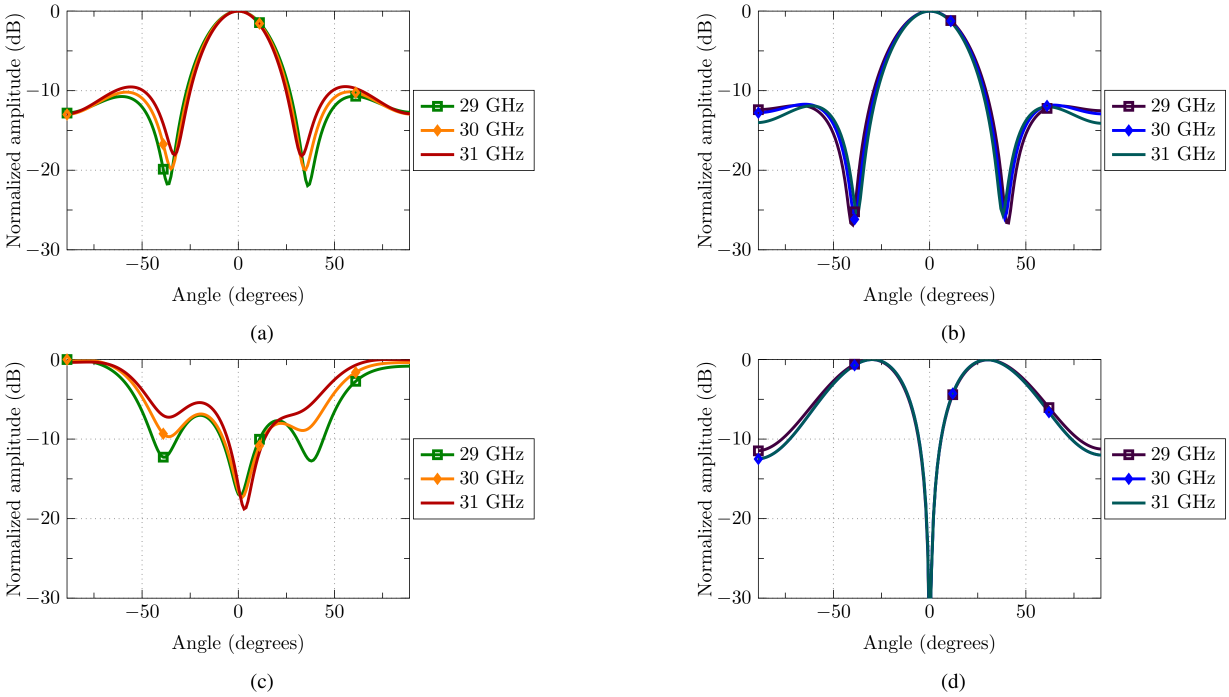


Fig. 2. Top view and perspective view of the antenna without and with the lid.

In the past, mainly hollow waveguide feeding networks have been one alternative to solve the aforementioned issues. Nevertheless, achieving good electrical contact among the building blocks is not especially easy at millimeter-wave frequencies.

From 2010s, the use of Gap Waveguide (GW) technology has become popular, as it can ensure the confinement of the field in non-contact metal structures under certain conditions [6]-[20].



(a) (b) (c) (d)

Fig. 3. Simulated normalized radiation patterns (a) ϕ=0° (port 2); (b) ϕ=90° (port 2); (c) ϕ=0° (port 1); (d) ϕ=90° (port 1).

. Under these premises, this paper presents a circularly-polarized single-layer Ka-band monopulse slot array antenna, whose corporate-feed network and cavities are housed in a bed of nails, characteristic of the GW. The design and simulated results are presented in the following.

II. 2×2 UNIT CELL DESIGN

The unit cell design is presented in Fig. 1 and Fig. 2. It consists of 4 antennas placed in a two-dimensional manner, composing a 2×2 array. The total array size is 17 mm×16 mm×16 mm. The radiating cavities are cube-shaped, chamfered along two of their edges. This type of cavities have already been used in this working band in other works [28]-[30], although in those cases they were actually cylindrical cavities. The separation between the antennas is 8.1 mm on the horizontal axis and 7.6 mm on the vertical axis. Since the central working frequency of the antenna is 30 GHz, the elements are spaced $0.81\lambda_0$ and $0.76\lambda_0$, respectively.

These four cavities are fed by a combination of different GW waveguides: ridge (RGW) and groove (GGW) gap waveguides. Building distribution networks combining both waveguide types, provides an interesting phasing arrangement that was first exhibited in [31] and later widely used [32]-[34].

In a monopulse antenna, a sum pattern and a difference pattern are desired. That is, a pattern with a radiation maximum in the broadside direction (ϕ=0°, θ=0°), and another pattern presenting a null in that same direction. In order to excite the antennas in such a way to achieve these two types of patterns, the distribution network comes into play. Port 2, which is a port located at the bottom of the antenna, feeds the central GGW through a coupling slot located right in the center of the structure. The field, thanks to its orientation, barely couples into the lateral GGW as will be demonstrated in the simulations section. Thus, the entire signal is distributed evenly to the 4 RGWs that finally excite the four chamfered cavities. In this way the sum diagram is obtained.

Regarding the difference pattern, it is achieved by exciting port 1, connected to the lateral GGW. The first divider, based on an E-plane GGW splitter, introduces a 180° phase shift on both sides of the divider. After that, the field is evenly distributed, but this phase shift is no longer undone and it is what makes the two upper cavities have a 180° phase-shift with respect to the lower ones. In this way the difference pattern is obtained.

A linearly-polarized (LP) version of this antenna was firstly and briefly described in [35]. Here the antenna concept has been redesigned to generate circular polarization (CP) by replacing the cylindrical cavities with square ones and thanks to the chamfered edges. Interestingly, despite this new attractive feature for the antenna, its dimensions are even smaller than the LP version, thus achieving a design as compact as that one and with the advantage of providing CP.

III. SIMULATED RESULTS

Preliminary results for this cell are presented below. First, Fig. 3 shows the diagrams in the main cuts (ϕ=0° and ϕ=90°) for both ports. The sum pattern is the one obtained for port 2, and normalized diagrams with stable behavior are obtained for different frequencies. The maximum directivity achieved in both cases is 14.5 dBi for the sum diagram and 11.5 dBi for the difference. As expected, the difference diagram has 3 dB less than the sum diagram. The difference diagram that

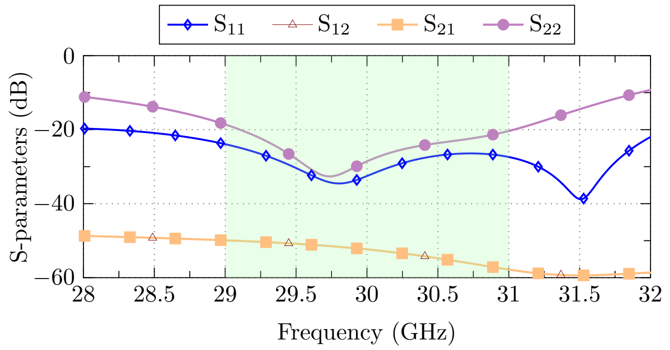


Fig. 4. Simulated S-parameters of the antenna

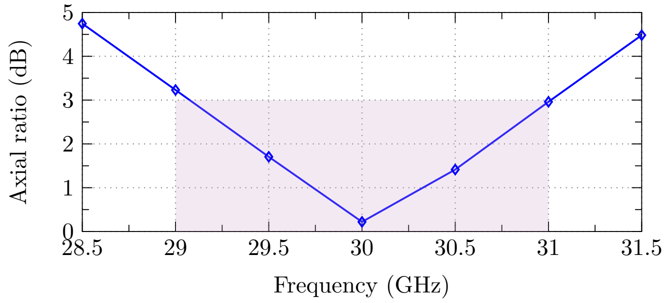


Fig. 5. Simulated axial ratio

makes sense to analyze is the ϕ=90° cut. To obtain a difference pattern at the ϕ=0° cut would imply a third port and a more complex network than the one presented here, which could be addressed in a larger antenna.

Fig. 4 illustrates the S-parameters preliminary results. Very good matching is obtained in this unit cell for both ports (<-20 dB). Likewise, as noted in the previous section, the decoupling between the input ports is considerable, with an isolation of more than 50 dB. Finally, a key performance of this antenna is its circular polarization. Recall that it has not been necessary to add an extra layer as is the usual solution found in the literature. In this case the radiating cavities excited by a network integrated in a single layer is able to provide circular polarization as shown in Fig. 5. Although this unit cell does not stand out for a large axial ratio (AR) bandwidth, it at least meets the typically accepted thresholds of an AR below 3 dB for the working band (29 GHz to 31 GHz).

IV. CONCLUSION

A compact 2×2 monopulse Ka-band antenna with circular polarization is presented. A combination of ridge gap and groove gap waveguides has been used to build the monopulse network comparator. The working frequency is from 29 GHz to 31 GHz, a typical band for transmitting antennas in SOTM applications. The axial ratio remains below 3 dB for the band of interest. These promising preliminary results should be validated, ideally on a larger antenna, which would be possible thanks to the scalability of the presented design.

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