A Ka-band Compact Single-Layer Gap Waveguide Monopulse Slot Array Antenna

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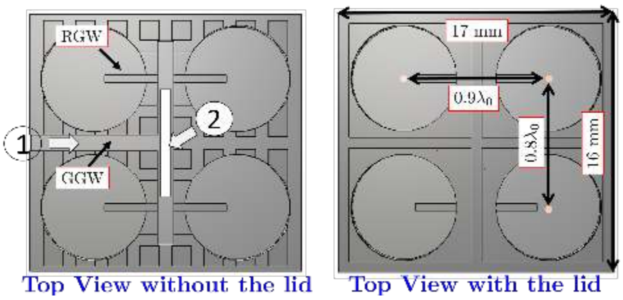
Abstract

This paper presents a gap-waveguide-based compact monopulse array antenna for millimeter-wave tracking applications at Ka-band (27.5 to 30.5 GHz). A low-loss Magic-Tee is designed to be used in a monopulse comparator network. 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. Simulated results show bandwidths of 10% with input reflection coefficients better than -12 dB for the sum and difference ports over the frequency band of interest. Besides, the isolation between sum and difference ports is more than 50 dB. The simplicity of the design and the fact that it is housed in a single layer permit easy scaling to larger arrays.

1 Introduction

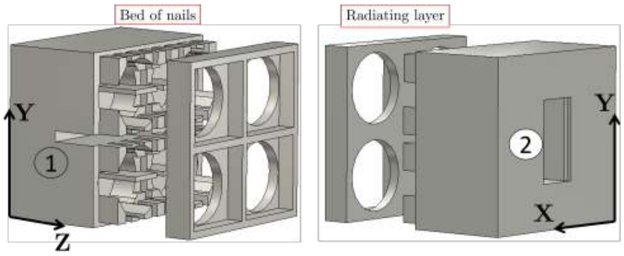
Millimeter-wave monopulse radars are attractive for high resolution tracking applications. They can provide a narrow beamwidth for high angular accuracy with a relatively small aperture size. To obtain a narrow beamwidth for high-gain monopulse tracking radars, reflector antennas are good candidates, thanks to their ease design and good performance [1]-[2]. However, reflector antennas are bulky structures that are usually not suitable for implementation in modern communications systems. Alternatively, microstrip or SIW antennas can be a low-profile and low-cost alternative to reflector antennas [3]-[4]. However, a complicated design, the need for low-loss substrates, and a narrow bandwidth are some of the drawbacks of the substrate-based antennas. A trade-off design between these two alternatives are the full-metal planar array antennas, which can provide high-gain performance together with compact and low-profile structure for monopulse applications. Likewise, there are certain challenges that are not minor; first, corporate-feed networks are much more bulky than those of printed technology; second, obtaining as good antenna efficiency as that achieved by parabolic reflectors is a notable challenge.

In the past, different transmission line technologies have been used to realize planar array antennas for monopulse applications, mainly hollow waveguide feeding networks. Nevertheless, achieving good electrical contact among the building blocks is not especially easy at millimeter-wave frequencies due to the miniaturization of the devices, proportional to the increase in frequency.



Top View without the lid
Top View with the lid

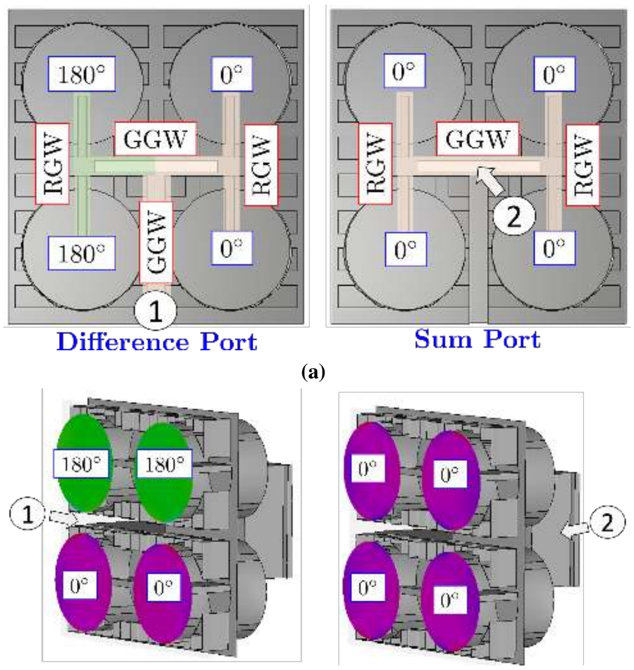
Figure 1. Top view of the antenna without and with the lid.



Exploded view (top)
Exploded view (bottom)

Figure 2. Exploded view (top and bottom) of the 2×2 array antenna.

In light of this problem, different technologies have been used to overcome that issue, such as diffusion bonding or, more recently, several additive manufacturing (AM) techniques. Nevertheless, diffusion boding is a hardly accessible and expensive technique, and the AM has certain challenges ahead, as to assure surfaces free of roughness to reduce conductor loss. In the last decade, the use of Gap Waveguide (GW) technology has become popular, as it can ensure the confinement of the field to non-contact metal structures under certain conditions [5, 6, 7]. Under these premises, this paper presents a 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.



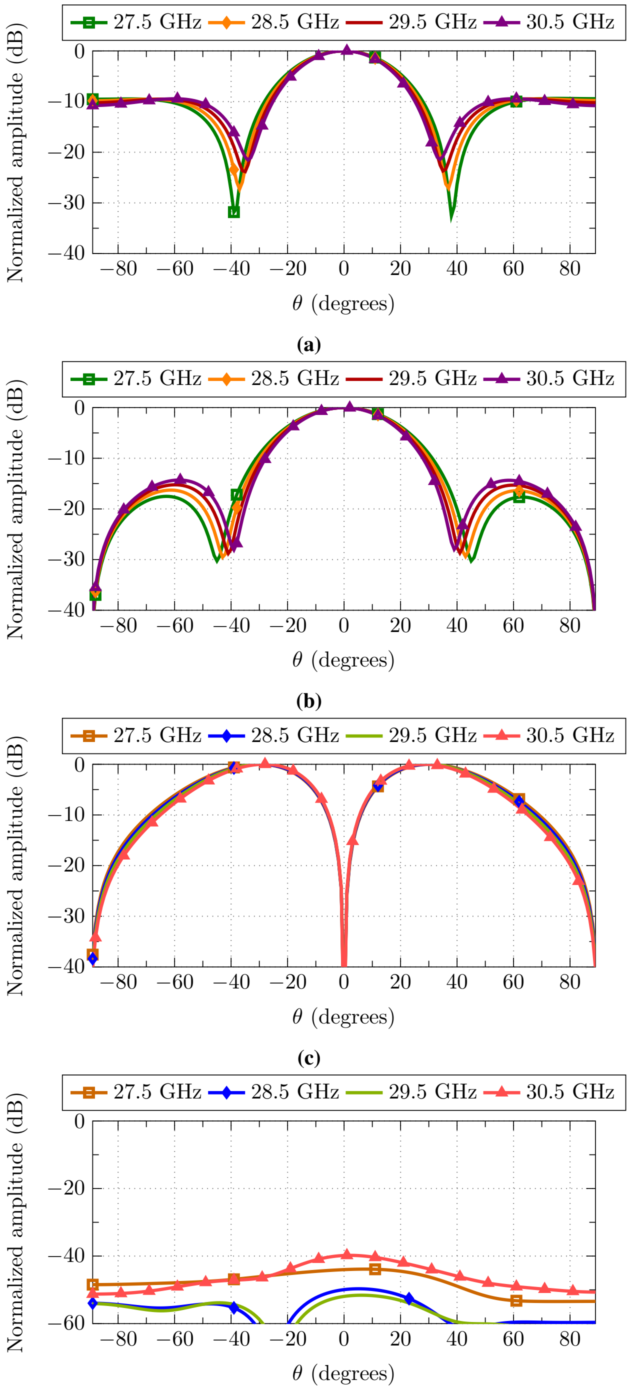
(a)

(b)

Figure 3. (a) Description of the RGW-GGW network and (b) phase performance of the antenna.

2 2×2 Unit Cell

The 2×2 cell of this monopulse antenna consists of 4 cylindrical cavities housed in a bed of nails. Figs. 1 and 2 show a front-view and a perspective view of the proposed cell, respectively. The antenna consists of two ports, one sum (port 2) and one difference (port 1). The antenna has horizontal dimensions of 17 mm x 16 mm, and the total height is less than 1.5 cm. The radius of the cylindrical cavities are $0.6\lambda_0$ (where λ_0 is 10 mm, wavelength at free space of 30 GHz), and they are separated by $0.9\lambda_0$ and $0.8\lambda_0$ in the X and Y axes, respectively. The differential port is labelled as 1 which is located on the side of the antenna. This port is connected to a 1 to 4 corporate-feed network. The first balanced power divider is a narrow-wall GGW splitter that introduces a 180° phase imbalance between both arms. Then, the next splitter is a GGW to RGW, which divides the signal with equal amplitude and phase between both arms and finally feeding the cylindrical cavities. This behavior of the GGW-RGW networks was first implemented in [8] and later used in other Ka-band antennas, but never in a sum-difference antenna. The freedom to combine the GGW-RGW consecutively or alternatively allows this unique feature of phase unbalance possibility in the dividers. Finally, port 2 is the sum port and is located at the bottom of the antenna. The port is coupled with a slot that directly excites the GGW in the center. Next, the path followed is the same as described above, so ultimately all cylindrical cavities are excited with the same phase and amplitude. A sketchy description of the distribution networks and the phases of the cavities in each case can be seen in Figs. 3a and 3b.



(a)

(b)

(c)

(d)

Figure 4. Simulated radiation patterns; in (a) and (b) the XZ and YZ planes of the sum port ($\sum$) are shown, in (c) and (d) the XZ and YZ planes of the difference port (Δ).

3 Simulated results

Figs. 4 to 6 show different simulated results on the operation of the antenna. First, two cuts of the radiation patterns are shown, in ϕ=0° (XZ-plane) and ϕ=90° (YZ-plane). Figs. 4a and 4b show the sum patterns, Figs. 4c and 4d the difference patterns. Notice the good stability of all patterns over the entire frequency range of more than 10%.

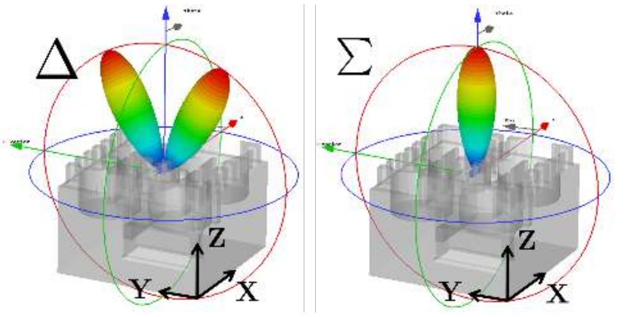
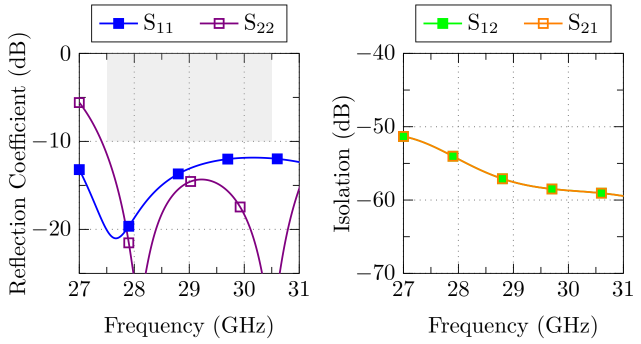


Figure 5. 3D simulated radiation patterns in linear scaling. Left figure correspond to difference pattern, right one to sum pattern.



(a) **(b)**

Figure 6. Simulated reflection coefficients. (a) Reflection coefficient of each port and (b) isolation between ports.

Besides, for the sake of better illustration, Fig. 5 shows the 3D-pattern in each case. Finally, Fig. 6a exhibits the good matching in both cases and more importantly the great isolation between the ports, above 50 dB in the entire working band (Fig. 6b).

4 Conclusions

In this paper, a compact gap waveguide monopulse antenna slot array is proposed. Its main novelty lies in its great compactness, unusual in the field of full-metal monopulse antennas. The antenna consists of one single layer of metallic plate. The function of a monopulse comparator is realized by combining different waveguides of the GW technology, i.e, GGW and RGW. The single-layer antenna array can maintain a higher aperture efficiency in an 4-element array at most. Simulated results proves the feasibility of the idea pending the experimental demonstration with a larger array.

5 Acknowledgements

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