

Research Article

Ka-Band Slot-Microstrip-Covered and Waveguide-Cavity-Backed Monopulse Antenna Array

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A slot-microstrip-covered and waveguide-cavity-backed monopulse antenna array is proposed for high-resolution tracking applications at Ka-band. The monopulse antenna array is designed with a microstrip with 2×32 slots, a waveguide cavity, and a waveguide monopulse comparator, to make the structure simple, reduce the feeding network loss, and increase the frequency bandwidth. The 2×32 slot-microstrip elements are formed by a metal clad dielectric substrate and slots etched in the metal using the standard printed circuit board (PCB) process with dimensions of $230 \text{ mm} \times 10 \text{ mm}$. The proposed monopulse antenna array not only maintains the advantages of the traditional waveguide slot antenna array, but also has the characteristics of wide bandwidth, high consistence, easy of fabrication, and low cost. From the measured results, it exhibits good monopulse characteristics, including the following: the maximum gains of sum pattern are greater than 24 dB, the 3 dB beamwidth of sum pattern is about 2.2 degrees, the sidelobe levels of the sum pattern are less than -18 dB, and the null depths of the difference pattern are less than -25 dB within the operating bandwidth between 33.65 GHz and 34.35 GHz for $\text{VSWR} \leq 2$.

1. Introduction

Millimeter-wave monopulse antenna arrays have received considerable attention in the radar tracking systems owing to their ultrahigh resolution [1, 2]. Waveguide slot antenna arrays [3] or microstrip antenna arrays [4, 5] are commonly used in traditional monopulse tracking systems. Waveguide slot antenna arrays possess several unique advantages, such as low loss, low coupling effect, low cross-polarization, high radiation efficiency, high polarization purity, high frequency operation, and high power handling capability, but they are of narrow bandwidth and high cost and not suitable for mass production [6–9]. Microstrip antenna arrays have been widely used in monopulse system, showing benefits including high integration capability, low cost, and ease of mass production [4, 5]. However, they have difficulty in achieving low sidelobe levels and high radiation efficiencies

due to the strong mutual coupling and spurious radiation among the monopulse comparator, feed network, and radiation elements [10]. Furthermore, the loss in a microstrip line becomes much more significant due to the high conductor loss, dielectric loss, and radiation loss in the millimeter wave and upper bands [11, 12]. To overcome the drawbacks of the conventional waveguide slot and microstrip antenna arrays, dielectric-covered slot arrays were investigated by Montisci et al. [13–16] and Zheng et al. [17], but they did not tell about the monopulse characteristics. Recently, substrate integrated waveguide (SIW) technology based monopulse antenna array is proposed by Cheng et al. [18]. Since SIWs can not only preserve the advantages of conventional rectangular waveguide but also be implemented with printed circuit board (PCB) process, the monopulse comparator and the radiation elements of this array are all integrated on single dielectric substrate [18].

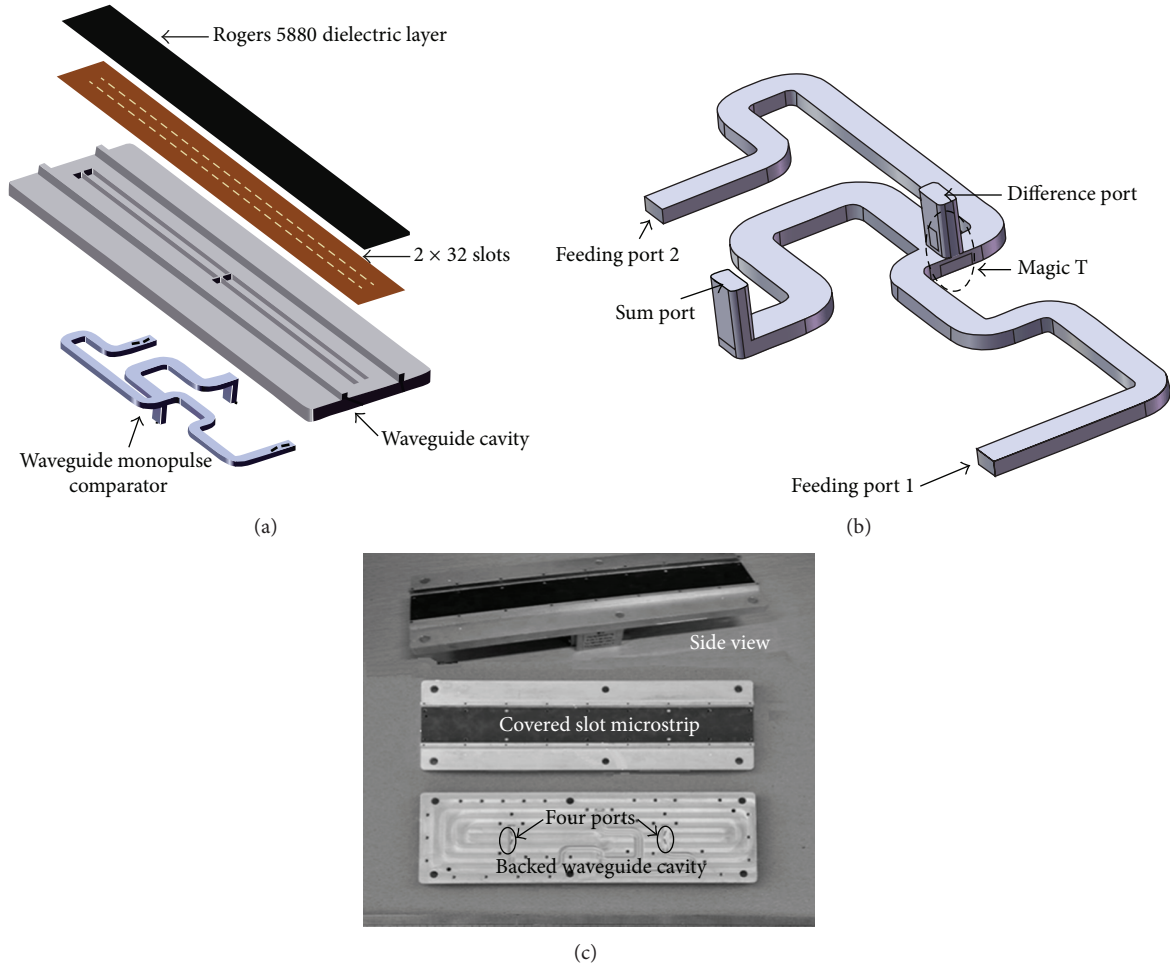


FIGURE 1: Structure of the monopulse antenna array. (a) Exploded view, (b) waveguide monopulse comparator, and (c) prototype.

This work experimentally investigates a Ka-band slot-microstrip-covered and waveguide-cavity-backed monopulse antenna array composed of a microstrip with 2×32 slots, a waveguide cavity, and a waveguide monopulse comparator. Experimental results exhibit good monopulse characteristics in terms of wide bandwidth, maximum gains, 3 dB beamwidths, sidelobe levels, and null depths, which combines the advantages of the waveguide slot antenna array and microstrip antenna array while eliminating their disadvantages.

2. Design, Fabrication, and Test

The structure of the monopulse antenna array is shown in Figure 1, which consists of a microstrip with 2×32 slots, a waveguide cavity, and a waveguide monopulse comparator. The copper slot microstrip (0.018 mm thick) is fabricated on a Rogers 5880 dielectric layer (0.254 mm thick, $\epsilon = 2.2$). Four subarrays are connected to the four ports of the feed network. The waveguide monopulse comparator is realized by using a magic-T to obtain a sum and difference feeding network, as shown in Figure 1(b). Each subarray was formed by 1×16 slot-microstrip elements with a Taylor amplitude distribution

[19]. In this study, the centre distance between two slots is $\lambda_g/2$ (6.48 mm), where λ_g is the guided wavelength. The slots are placed at a quarter of the guided wavelength ($\lambda_g/4$) from the shorted wall. They are 0.6 mm in width and 3.2 mm in length, and the approximate offset value from the waveguide centreline is calculated at 34 GHz using the equivalent circuit mode or termed Elliott's method [20, 21]. Elliott's method has been successfully used for waveguide slot antenna arrays [22–28], although it yields the offset value to be approximately effective only. In order to get more accurate offset value and fully account for the coupling effect, it is necessary to optimize the monopulse antenna array by full-wave simulation. Table 1 lists the final optimized offset values using both Elliott's method and FEM based 3D full-wave simulator Ansys HFSS.

The size of the groove guide in the waveguide cavity is 2.74 mm \times 5.48 mm. The height of the metal walls is 4 mm. The cross-section dimension of the waveguide in this design is 3.556 mm \times 7.112 mm (WR-28). Four aperture-coupled slots (with 3.6 mm \times 0.6 mm) are used to excite the 2×32 slot-microstrip elements at the feeding ports 1 and 2 of the monopulse comparator, as shown in Figure 1. For the monopulse antenna array, loss is unavoidable

TABLE 1: Offset value of the subarray slots (16 slot-microstrip elements) from the waveguide centreline, unit in millimeter.

| Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|--------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Offset | 0.29 | 0.30 | 0.31 | 0.33 | 0.36 | 0.39 | 0.43 | 0.47 | 0.51 | 0.55 | 0.58 | 0.61 | 0.64 | 0.65 | 0.67 | 0.67 |

in the feeding network and dielectric. However, in our case, the loss is limited by the metal waveguide based monopulse comparator and very low loss tangent (0.0009) of Rogers 5880 dielectric layer in our design. Note that this design may lead to mass production, reduce the cost, and increase the frequency bandwidth as compared with the standard slotted waveguide technology. The monopulse antenna array is assembled by brazing the waveguides (including waveguide cavity and waveguide monopulse comparator) and using conductive adhesive to adhere the copper slot microstrip and waveguide cavity together. To avoid weak electrical contact between PCB and waveguides during the annealing process, screws are also used to secure stem attachment between them.

Figure 2 shows the measured VSWR of the sum port and the difference port. The results show that the measured bandwidth (VSWR ≤ 2) of the monopulse antenna array is 700 MHz (from 33.65 GHz to 34.35 GHz) for both the sum port and the difference port. The measured normalized E-plane sum and difference radiation patterns and H-plane sum radiation pattern at 34 GHz are shown in Figure 3. The sum pattern exhibits a 2.2-degree 3 dB beamwidth and -18 dB sidelobe level. The normalized null depth of the difference pattern is less than -40 dB. Table 2 summarizes the measured maximum gains and the null depths at different frequencies. It is seen that the maximum gains of sum pattern are greater than 24 dBi and the null depths of the difference pattern are less than -25 dBi within the operating bandwidth between 33.65 GHz and 34.35 GHz for VSWR ≤ 2 . The radiation efficiency of the Ka-band slot-microstrip-covered and waveguide-cavity-backed monopulse antenna array is 85.3% which is significantly higher than that of the microstrip antenna array.

Such Ka-band slot-microstrip-covered and waveguide-cavity-backed monopulse antenna array has better performance in bandwidth than that in conventional waveguide slot monopulse antenna arrays, better sidelobe levels and radiation efficiency, and high polarization purity than those in conventional microstrip monopulse antenna arrays. For instance, the bandwidth of the conventional aperture-coupled waveguide slot monopulse is just 1% [11], while it is greater than 2% for the proposed monopulse antenna. In addition, the radiation efficiency of the conventional microstrip monopulse antenna array is about 40%, whilst it is greater than 80% for the proposed monopulse antenna. The first reason is that the slot-microstrip-covered dielectric above a metal ground can increase the impedance bandwidth of the monopulse antenna array. Furthermore, waveguide has lower loss and is more suitable for high frequency transmission than microstrip line.

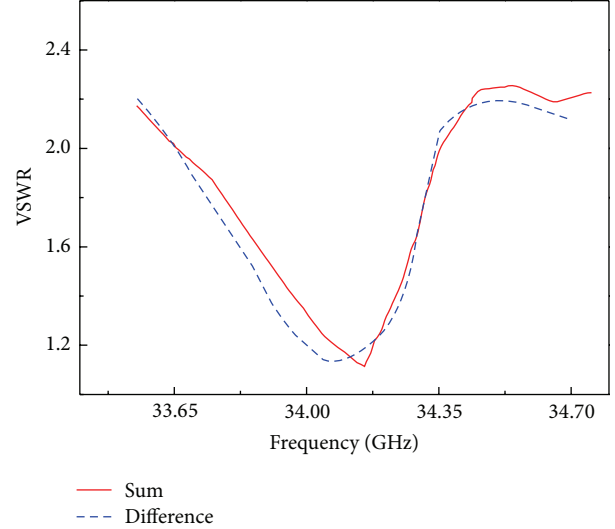


FIGURE 2: Measured VSWR.

TABLE 2: Measured maximum gains and the null depths at different frequencies.

| f (GHz) | Maximum gain (dBi) | Null depth (dBi) |
|-----------|--------------------|------------------|
| 33.65 | 25.24 | -28.1 |
| 33.8 | 24.79 | -37.3 |
| 34 | 24.84 | -29.9 |
| 34.2 | 24.51 | -26 |
| 34.35 | 24.55 | -25.7 |

3. Conclusion

Ka-band slot-microstrip-covered and waveguide-cavity-backed monopulse antenna array has been designed and experimentally investigated in this paper. The measured results show that the maximum gains are greater than 24 dBi, the 3 dB beamwidths are about 2.2 degrees, the sidelobe levels are less than -18 dB, and the null depths are less than -25 dBi, during the 700 MHz operating frequencies. These results demonstrate that the slot-microstrip-covered and waveguide-cavity-backed monopulse antenna array has a broad bandwidth, high consistence, ease of fabrication, and low cost, and it can be successfully applied to millimeter-wave monopulse radar systems.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

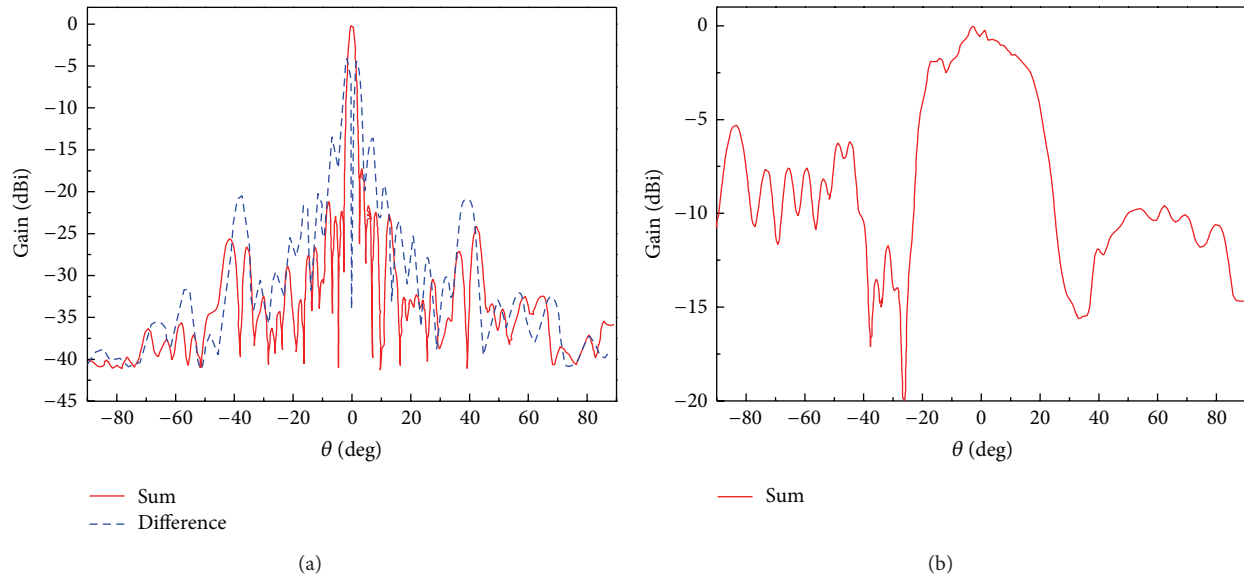


FIGURE 3: Measured normalized (a) E-plane sum and difference radiation patterns and (b) H-plane sum radiation pattern at 34 GHz.

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