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DESIGN OF A WIDEBAND MONOPULSE ANTENNA USING FOUR CONICAL HELIX ANTENNAS

H. Gharibi* and F. H. Kashani

Department of Electrical Engineering, Iran University of Science and Technology (IUST), Narmak, Tehran, Iran

Abstract—A novel S-band monopulse antenna with four conical helix antennas on a microstrip substrate comparator is designed, fabricated and measured. Conical helix antenna height is 3λ, and comparator size is $130\,\text{mm} \times 150\,\text{mm}$. The bandwidth (SWR $< 2\,\text{dB}$) of the antenna is 21.3% with an operating frequency range of 2.7 GHz–3.35 GHz. The maximum gain of the sum pattern is 17.4 dB, and the null depths of the difference pattern are less than $-30\,\text{dB}$.

1. INTRODUCTION

Monopulse is one of the most efficient methods in tracking radars. Using a reflector antenna, four horn antennas as feed network and waveguide monopulse comparator has been a common way for designing this radar for years [1]. However, large size and difficulty in instruction led to applying other antennas such as microstrip and SIW antennas in designing monopulse radar [2–5]. A low-cost K-band microstrip patch monopulse antenna was designed by Jackson [2]. This antenna array was formed by 2×2 elements and placed at the central part surrounded by the comparator network. A microstrip monopulse antenna in millimeter-wave frequency was designed in [3]. A low-cost monopulse radial line slot antenna with slots placed on the upper plate in concentric rings was introduced in [4]. In this array, the comparator network was placed at the center of the antenna. Cheng et al. designed a dual V-type linearly tapered slot antenna (DVLTSA) in millimeter-wave band [5].

In this paper, helical antenna is used for its good specification such as high gain and circular polarization. First, S band conical helix antenna with the optimum gain and sidelobe level is designed. Then,

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* Corresponding author: Hassan Gharibi (gharibi.hasan@gmail.com).

a network with two microstrip comparators is designed for deriving sum and difference patterns. The first comparator includes three rat-race couplers and four conical helix antennas. The second microstrip comparator is designed with four branch couplers, which is symmetrical and has a better performance.

2. DESIGN OF AN OPTIMUM CONICAL HELIX ANTENNA

Lipman and Harlev analyzed long conical helix antenna and obtained conditions for designing helical antenna with high gain and low sidelobe level [6]. Monopulse antenna for good performance must have high gain and low SLL. However, there is a trade-off between the gain of the antenna and its sidelobe level where higher gain can cause higher sidelobe level, too. Using Method of Moments formulation for helical antennas, parameters of the antenna were optimized. An antenna with 3λ length and 25 turns was chosen for the monopulse radar. Figure 1 shows the structure and radiation pattern of the designed antenna.

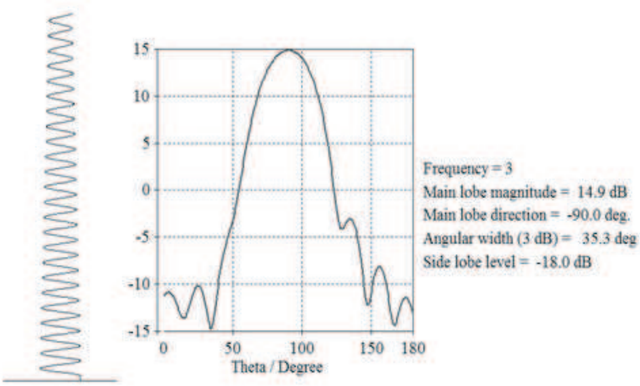

Figure 1. Structure and radiation pattern of the designed conical helix.

3. IMPEDANCE MATCHING TO MICROSTRIP LINE

Matching the conical helix antenna to 50 ohm microstrip line is one of the challenging requirements since monopulse comparator is a microstrip network. Input impedance of the designed antenna is shown in Figure 2. It includes both real and imaginary parts and has a smooth response over the frequency band. Impedance of the antenna was modeled with a series RC circuit with proper values. Microstrip line theory was used for the matching network design and optimization. The antenna and matching line is shown in Figure 3. It can be seen that matching network is so simple and that the achieved result is very good. Return loss of the antenna with matching line is shown in Figure 4.

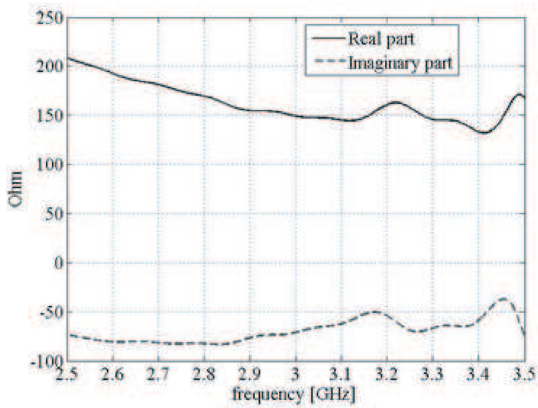

Figure 2. Input impedance of the designed conical helix antenna.

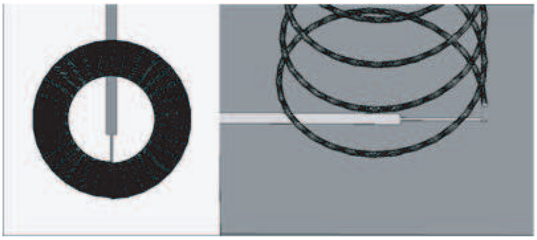

Figure 3. Conical helix antenna matched to microstrip line.

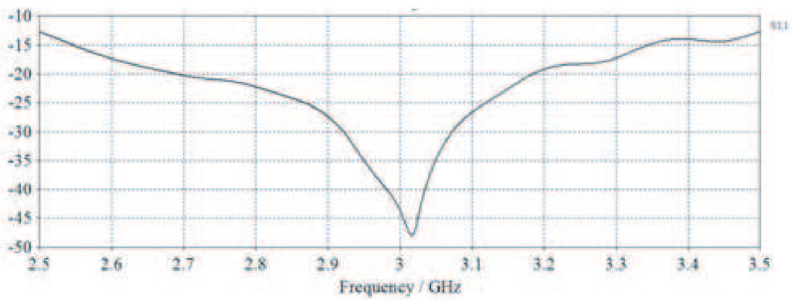

Figure 4. Return loss of the conical helix with microstrip matching line.

4. COMPARATOR TYPE I

Rat-race couplers can be used for designing monopulse comparator and creating sum and difference patterns in microstrip structure [7]. Rat-race couplers are designed for working in 3 GHz in the first comparator in microstrip substrate. Specifications of the chosen substrate are dielectric constant 2.7, thickness 0.787 mm and loss tangent 0.0005. 50 ohm line width in 3 GHz is 2.4 mm and matching line width equal to 0.6 mm. This comparator includes three rat-race couplers, one 3 dB T-junction Power Splitter, four Impedance matching lines, four feed lines, and three ports. The size of the comparator is 140 mm $\times$ 150 mm, and the conical helix antennas 0.8λ (80 mm) away from each other. This comparator structure is shown in Figure 5.

After adding conical helix antennas to comparator network, monopulse antenna is completed. Figure 6 shows this structure in different views.

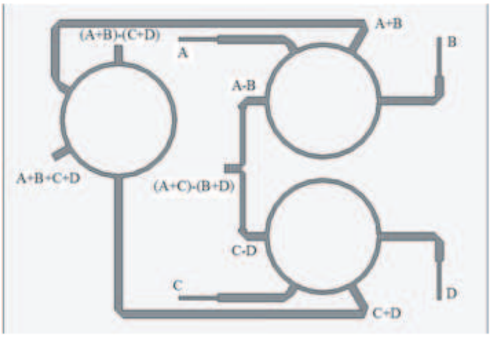

Figure 5. Monopulse comparator type I.

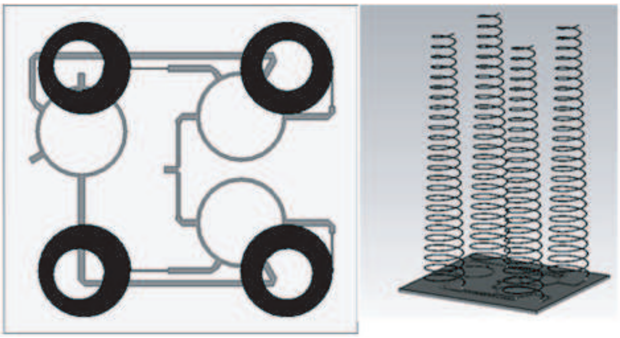

Figure 6. The first monopulse antenna with 4 conical helix antennas.

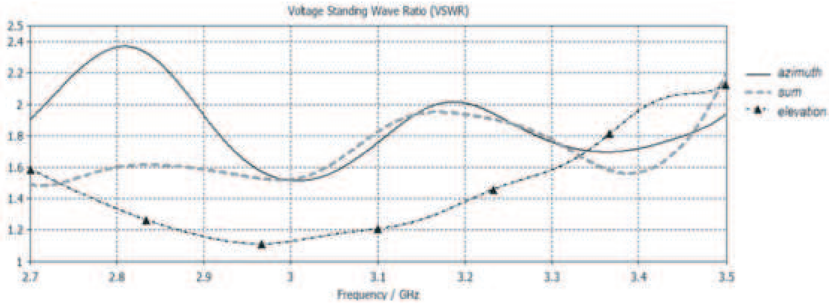

Figure 7. VSWR of the ports of the first monopulse antenna.

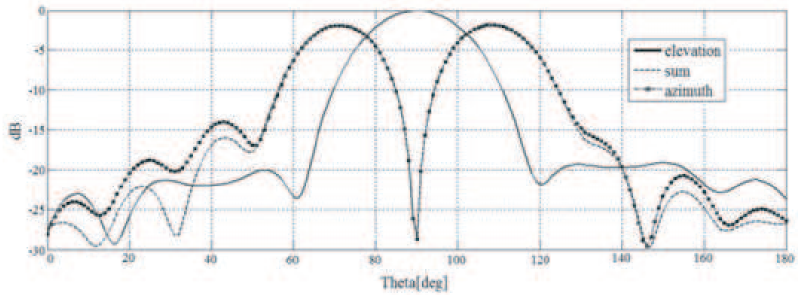

Figure 8. Radiation patterns of the first monopulse antenna.

Software CST was used for the simulation of the monopulse antenna. VSWR of the three ports is shown in Figure 7. Sum and difference radiation patterns are also shown in Figure 8.

This comparator does not show very good performances. Three ports are pin-fed, and VSWRs of all three ports are not low in frequency band. The bandwidth is only 9% and null-depth −28 dB.

5. COMPARATOR TYPE II

Wang et al. [8] designed a monopulse microstrip antenna array. Their comparator network is more symmetrical and used four 3 dB hybrid couplers. In this paper, branch-line couplers are used as 3 dB hybrid and conical helix antennas instead of microstrip antenna array. This comparator is shown in Figure 9. It also shows the positions of conical helix antennas and formation of the different signals in 4 ports. The microstrip substrate and line width are the same as those of the first comparator.

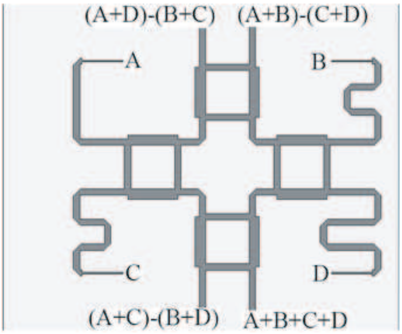

Figure 9. Monopulse comparator type II.

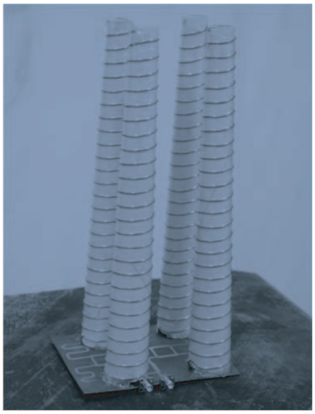

Figure 10. Prototype of the proposed antenna.

After placing conical helix antennas, the monopulse antenna is formed. Again, simulations are done with software CST. VSWRs of the ports are much lower than those of the first comparator, and the null depth is lower than $-30\,\mathrm{dB}$.

A prototype of the antenna is fabricated and shown in Figure 10. the measured results are shown in Figures 11–16. Figure 11 shows VSWR of the ports. The E plane sum pattern in Figure 12 and H plane sum pattern in Figure 13 are shown. E and H plane difference patterns are shown in Figures 14 and 15, respectively. The null depths are less than $-30\,\mathrm{dB}$ in both planes. The bandwidth of the antenna (VSWR < 2) is 21.3%. Antenna gain and null depth are calculated for some different distances between the helical antennas. The results are shown in Figure 16.

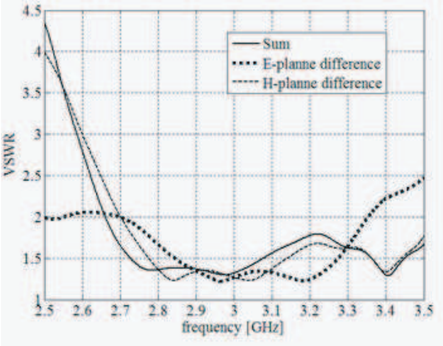

Figure 11. Measured VSWR.

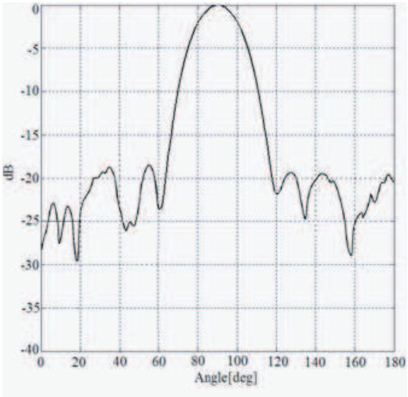

Figure 12. Measured E-plane sum pattern.

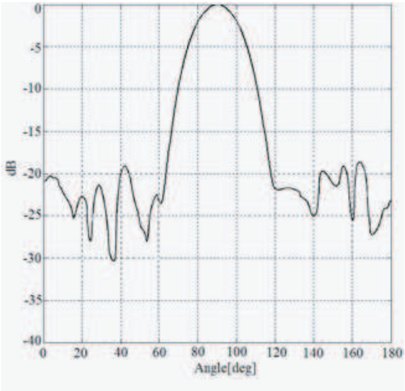

Figure 13. Measured H-plane sum pattern.

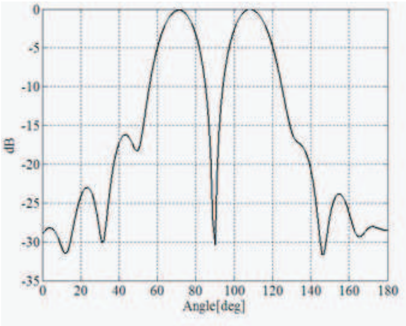

Figure 14. Measured E-plane difference pattern.

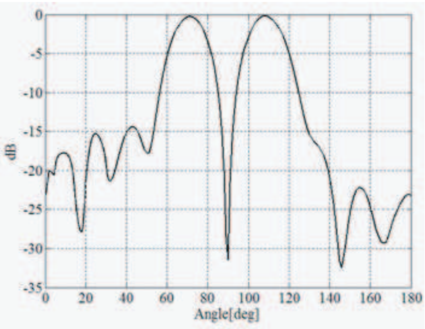

Figure 15. Measured E-plane difference pattern.

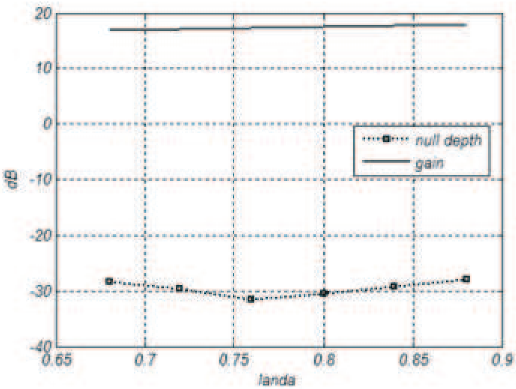

Figure 16. Gain and null depth versus space between the antennas.

6. CONCLUSION

In this paper, we propose a novel wideband monopulse antenna working in S band. It includes four conical helix antennas and a microstrip comparator. The proposed antenna has been fabricated and tested. The measured results approve the simulation ones and show that the antenna can be used in radar application.

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