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Engineering Realization of a Dual-Band Monopulse Antenna

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Abstract

The dual-frequency monopulse antenna is on the front end of the dual-mode seeker, and its geometrical and radiation characteristics both decide the performance of a system. In this paper, a new dual-frequency monopulse antenna is introduced; it adopts a compact slot radiator, a novel side-feed array, a waveguide feeding network in one dimension to reduce microstrip loss and other novel designs. After second optimization to overcome the engineering problem, an improved antenna is created, and it is divided into two parts to improve weldability and yield. The tested results show that the antenna has good monopulse characteristics in two bands at the same time, with an efficiency of 38％ and 45％, respectively. The experimental results demonstrate that this design is effective.

Keywords: dual-band; monopulse; efficiency; side-lobe

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1. Introduction

In recent years, dual-mode guidance systems have attracted the attention of many countries in the military field. A compound monopulse dual-band antenna receives and transmits electromagnetic waves on the front end of a guidance system, and their overall characteristics such as profile and efficiency affect the performance of the system.

The Cassegrain antenna with eight or nine horns is easy to design and realize, but its configuration is large and the efficiency is less than 20% in one band [1-2]. The waveguide slot antenna has better characters of high efficiency and good radiation performance compared with the parabolic antenna. A dual-frequency waveguide antenna with 1.8kg weight is introduced in [3], but it is too heavy and has lower yield, higher cost, complicated structure, and complex processing technology. Its efficiency is 40% in dual band, which limits its usage in compound guidance systems. The microstrip monopulse antenna exhibits a number of attractive qualities, but the feeding network loss is a drawback especially at higher frequencies. Therefore, designing a compound microstrip/waveguide monopulse antenna with high-efficiency and low-weight has become an important subject of studies in dual mode compound guidance systems. Recently, several combinations of microstrip/waveguide antennas have been studied, in which the microstrip monopulse array usually includes single- and double-layered types [4-5]. In the single-layered configuration, the microstrip radiator, comparator, and feeding network are all on a single substrate. This co-plane structure is simple and has attracted the interest of many researchers, but the comparator and feeding network are printed at the center part and the space between two sub-arrays is enlarged, which will lower the efficiency [6-11]. In the double-layered configuration, the upper substrate only includes microstrip arrays. The microstrip feeding network and the microstrip comparator are at the center of the lower layer, which is below the waveguide antenna of the other band. The microstrip antenna arrays are connected to the feeding network by the connector, passing through the waveguide array wall in the center and affecting its amplitude distribution. Furthermore, the arrangement of the microstrip array is a challenge in this design, which should achieve good radiation performance and cannot cover the waveguide radiating slots below.

In this paper, we introduce a novel microstrip/waveguide antenna, in which four novel designs are introduced to solve

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the problem mentioned above. Firstly, a novel side-feed array is designed by employing a shorting point in the center. Secondly, a compact slot patch is designed to fit the space between adjacent waveguide radiating slots. Thirdly, the waveguide feeding network in the E-plane replaces the microstrip network to decrease microstrip loss. Finally, an engineering problem of the phase unbalance brought by a nonuniform air layer is solved. The details are discussed as follows.

2. Configuration and Design

This novel antenna is comprised of four parts from top to bottom. An X-band radiating array with twenty microstrip series line arrays is on the first layer. The second layer is a K-band waveguide slot array, which acts as the ground of the microstrip antenna. A waveguide feeding network of an X-band in the E-plane is under the K-band array, and it is used to feed every line array by the connector. A waveguide comparator of two bands is on the bottom.

2.1. Microstrip Element

The substrate is mounted on the K-band antenna with screws, and the upper metallic surface of the K-band waveguide slot antenna acts as the ground of the microstrip array.

Based on the transmission line mode [12], the length (L) and width (W) of the rectangular patch are calculated by Equations (1)-(5):

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{1}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.246)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{2}$$

$$L_{eff} = \frac{C}{2 f_o \sqrt{\varepsilon_{reff}}} \tag{3}$$

$$L = L_{eff} - 2\Delta L \tag{4}$$

$$W = \frac{C}{2 f_o \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{5}$$

Where ε_{reff} and ε_r are the effective dielectric constant and dielectric constant of substrate, respectively, and h is the substrate thickness. The length of the patch calculated from the above equations for the 9.6 GHz patch is L = 10.3mm, which is bigger than the space between adjacent slots in the E-plane.

As shown in Figure 1, a compact slot patch is employed with the aim to not cover the waveguide slots below [13]. The adding slots on surface can increase the current route and thus lower the resonant frequency. After study, the length L = 7.1mm, the slots length l = 5.6mm, and the width w = 0.8mm. The width W = 8.9mm is for better cross-polarization suppression. Furthermore, two spirals are loaded for achieving good matching. w_f is the width of the feeding line, which is 2.2mm and designed to have a characteristic impedance of 80 Ω .

2.2. Microsrtrip Array

The Taylor synthesis method is used in the design of the microstrip feeding line. The ratio of the normalized currents is 0.36:0.58:0.81:0.90:1, which is realized by adjusting the width of the transformer next to the element. Because the impedance of the element is designed to be 80 Ω , a 138 Ω impedance transformation is added between the element and the feeding network as shown in Figure 2. In order to keep each element in-phase, the space between the adjacent elements is one medium wavelength at center frequency. Different from the traditional series array, the shorting point is introduced in the center while the feeding point is at the side, which has less of a negative effect on the surface amplitude distribution of the waveguide antenna below because the current at the side is rare.

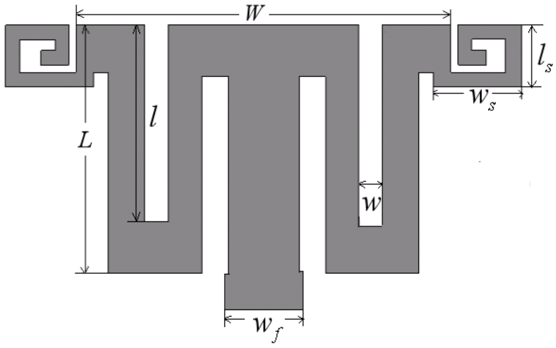


Figure 1. Configuration of the compact slot antenna

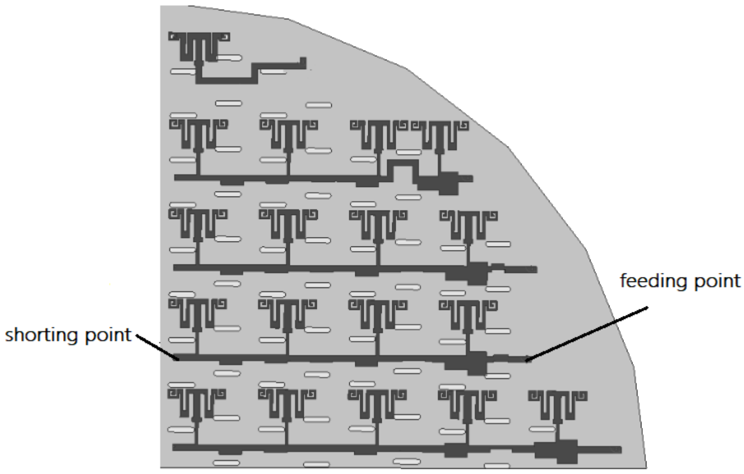


Figure 2. One quadrant of the proposed array

The configuration of one quadrant of the dual-band antenna is shown in Figure 2, and it is noted that the minimized microstrip line arrays can be placed between the adjacent waveguide slot arrays without covering the slots below. Furthermore, a waveguide feeding network in the E-plane direction is introduced as shown in Figure 3; it is around the aperture and feeds the series line array by the connector. The amplitude of the network is controlled by the inclined slot on the coupling waveguide below.

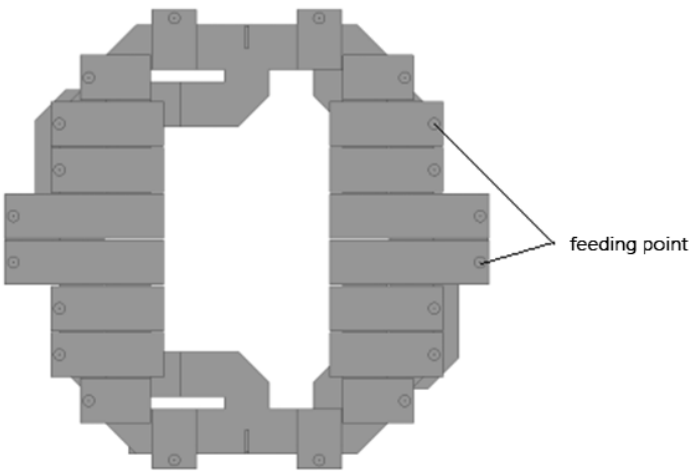


Figure 3. Configuration of the waveguide feeding network in the E-plane direction

2.3. Waveguide Slot Antenna

The primary radiator of the K-band is forty resonant longitudinal shunt arrays with 276 slots, which is divided into four subarrays. To feed every subarray, the four series resonant slot arrays with ten coupling slots are employed behind them. Because of the -20dB sidelobe requirement, a separable -30dB Taylor aperture distribution is used considering modeling errors, manufacturing tolerances, and so on. The offsets of cutting slots on the broad wall of the waveguide and the angles of the inclined slots on the feeding array are both the key factors to ensure the low sidelobe and high efficiency, which will be simulated in HFSS software.

In addition, the K-band radiator is under the X-band microstrip antenna, so the influence of the substrate should be considered when we calculate the offset and resonant length of the cutting slot. The simulated model of it is shown in Figure 4; for brevity, the details are omitted here.

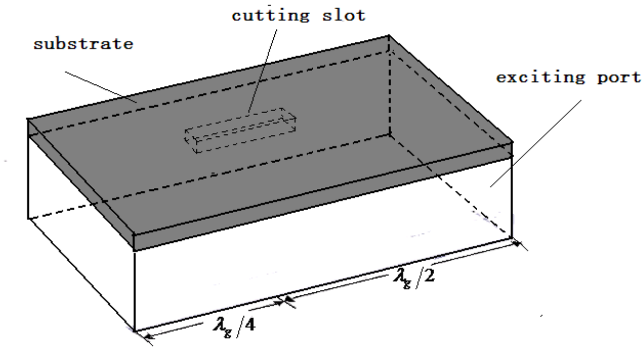


Figure 4. The model calculation of the cutting slot

2.4. Waveguide Comparator

The comparator is an indispensable part of any monopulse antenna and allows a system to form sum and differences patterns. Typically, the microstrip comparator is composed of microstrip delay lines, which will lead to significant loss especially in high bands. Therefore, the comparators of the two frequencies both use waveguide structures, which are constructed by 4 Magic-T, as shown in Figure 5.

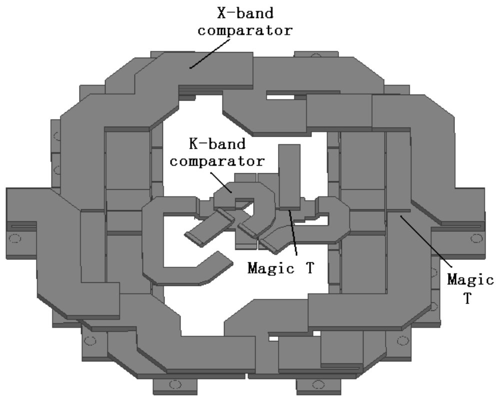


Figure 5. Structure of the two band comparators

In order to improve the weld ability and yield, the compound antenna except for the microstrip array is divided into two parts during the weld process: one is the comparator of dual bands, and the other is the rest. Furthermore, every sub-array is connected to the comparator by screws, and four spring lock washers are employed to reduce the energy leakage.

3. Experimental Study and Results

Figure 6 gives the photograph of the fabricated antenna with 29mm thickness and 900g weight, and the substrate is mounted on the waveguide antenna with some screws beside the feeding points. The surface of the waveguide acts as the ground of the microstrip array because the substrate is single-sided printed in our original design.

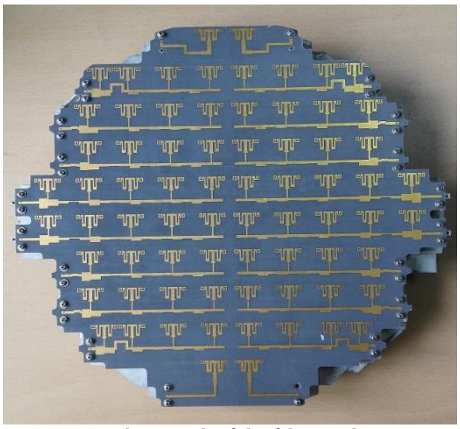


Figure 6. Photograph of the fabricated antenna

During the installation process, it is found that a nonuniform air layer between the substrate and waveguide antenna is imported. The introduction of this unexpected air layer alters the relative permittivity and the thickness of the microstrip antenna and causes phase unbalances among the microstrip series lines accordingly, which will deteriorate the radiation characteristics such as gain, side lobe, and so on. The measured results in an anechoic chamber confirm the predication. Thus, in order to overcome this engineering problem, eight metallic striplines with 4mm width below every microstrip feeding lines are introduced as shown in Figure 7, and they act as the ground of feeding lines and have little influence on the waveguide array.

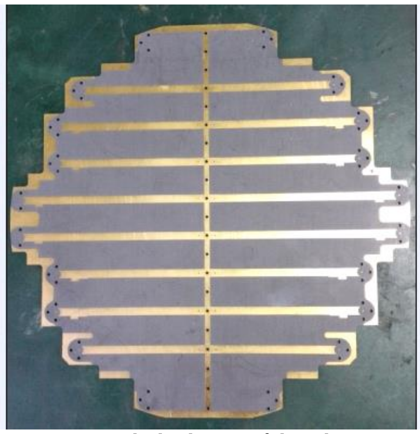
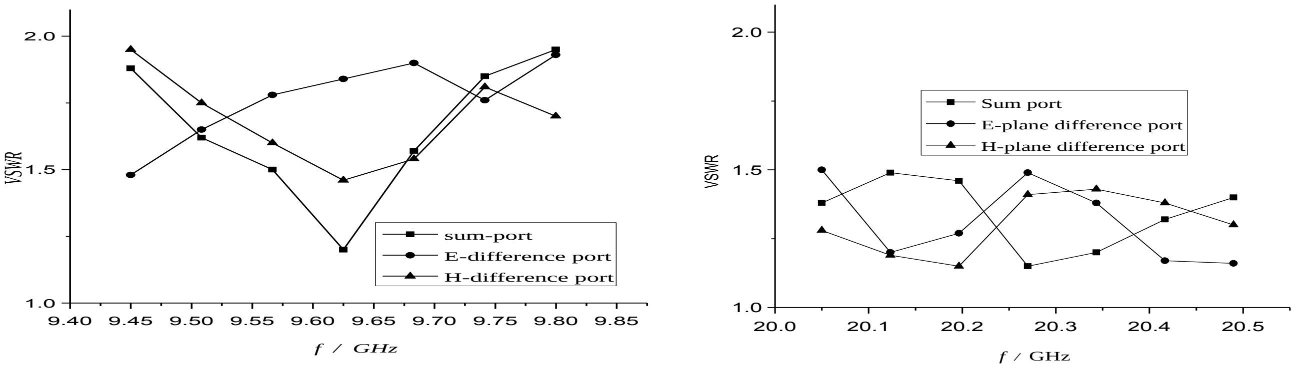


Figure 7. The back view of the substrate

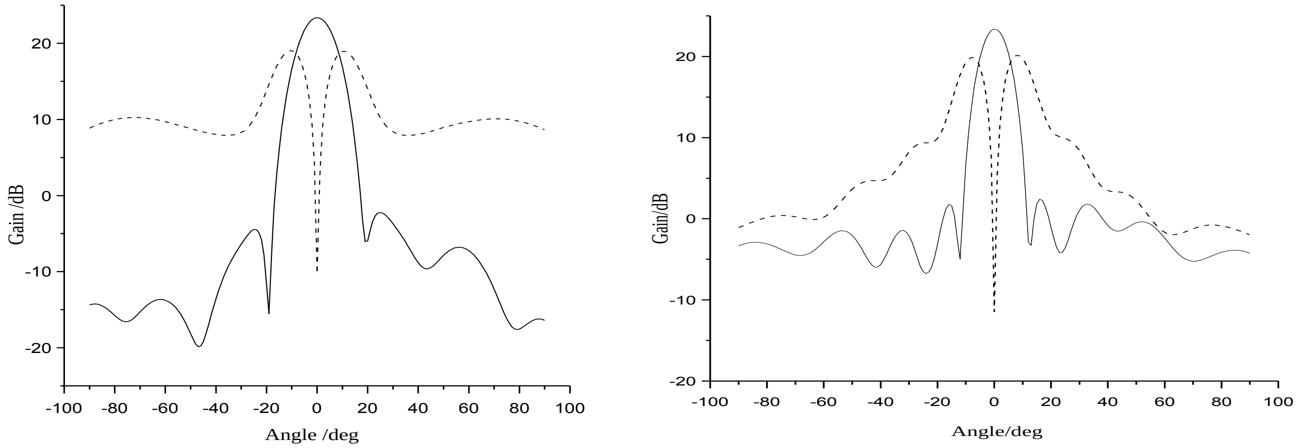
The improved antenna is tested by the Agilent 5244 vector network analyzer. The measured curves are presented in Figure 8. We can see that the *VSWR* of less than 2 covers 9.45GHz to 9.79GHz in the X-band, and the bandwidth is 3.5%. The *VSWR* of less than 1.5 covers 20.05GHz to 20.49GHz in the K-band, and the bandwidth is 2.1%. If the bandwidth of the K-band is broadened further, eight or more sub-arrays can be employed.



(a) X-band (b) K-band

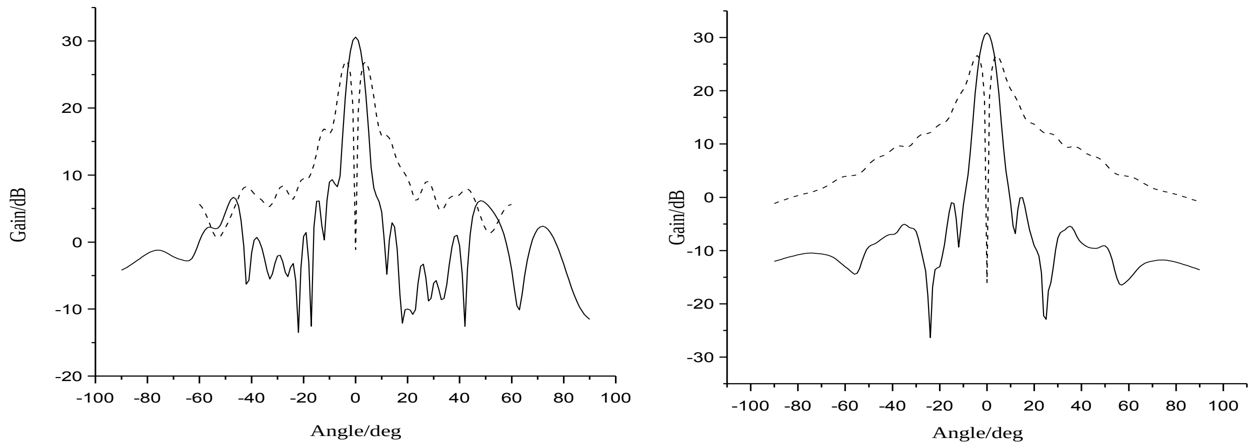
Figure 8. Measured *VSWR* for different ports

The antenna is measured in the anechoic chamber, and the patterns at center frequency of the two bands are shown in Figures 9 and 10, respectively. We can see that this proposed array exhibits good radiation characteristics in the two bands. The gain of the X-band is up to 23.4 dB, with about 38% efficiency. The sidelobes in the two main planes are below -19dB, and the null depths are less than -28dB. The connector connected to the microstrip array can affect feed phases; therefore, if the phase consistency and manufacturing tolerances of them can be properly controlled, the efficiency would be improved.



(a) E-plane (b) H-plane

Figure 9. Measured sum and difference patterns at X-band



(a) E-plane (b) H-plane

Figure 10. Measured sum and difference patterns at K-band

The K-band antenna demonstrates good monopulse characteristics as a single-band traditional waveguide antenna, whose null depths are lower than -30dB and sidelobe levels in two planes are below -22dB. The gain of the K-band is up to 30.5dB, with about 45% efficiency. Because of the influence of higher modes radiation of X-band, there is some sidelobe deterioration around ±45 degrees in the two main planes, as shown in Figure 10.

4. Conclusions

In this paper, a novel compound antenna for dual-band application is designed, fabricated, and tested. In order to construct this antenna, a compact element, a new feeding method of microstrip array, and a waveguide feeding network to decrease loss are all introduced. Furthermore, eight metallic mental striplines below every microstrip feeding line are employed to avoid the negative effects of the nonuniform air layer between the substrate and waveguide metallic surface. The measured results demonstrate that the proposed antenna has perfect monopulse characteristics in both bands, and the design is effective.

Acknowledgements

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References

1. X. Wu, "Developanment of Monopulse Common Reflector Dual Frequency Antenna," *Modern Radar*, Vol. 33, No. 11, pp. 56-62, 2011
2. Y. Cheng, "The Study on Multi-Band Co-Planar Antenna," *Journal of Microwave*, Vol. 22, No. 4, pp. 43-45, 2006
3. Y. Y. Liu and F. W. Yao, "Co-Aperture Dual-Band Waveguide Monopulse Antenna," in *Proceedings of International Symposium on Antenna and Propagation Conference*, pp. 685-687, 2013
4. G. Colangelo, "Shared Aperture Dual Band Printed Antenna," in *Proceedings of International Electromagnetic in Advanced Application Conference*, pp. 1092-1095, 2011
5. H. Wang and D. G. Fang, "A Compact Single Layer Monopulse Microstrip Antenna Array," *IEEE Transations on Antennas and Propagation*, Vol. 54, No. 2, pp. 503-509, 2006
6. K. Hemant, "Broadband Monopulse Microstrip Antenna for X-Band Monopulse Tracking," *IET Microwaves, Antennas and Propagation*, Vol. 12, No. 13, pp. 2109-2114, 2018
7. U. K. Revankar, "Low Sidelobe Light Weight Microstrip Antenna Array for Battlefield Surveillance Radars," in *Proceedings of IEEE National Radar Conference*, pp. 97-101, 2003
8. H. Hemant, "An Inverted Suspended Microstrip Antenna Array Integrated with Ratrace Comparator at X-Band for Monopulse Tracking," in *Proceedings of Asia-Pacific Microwave Conference*, 2016
9. D. G. Fang, "Novel Compact Microstrip Monopulse Antenna Array," *Nanjing Li Gong Daxue Xuebao/Journal of Nanjing University of Science and Technology*, Vol. 27, No. 5, pp. 473-477, 2003
10. S. M. Parinaz, "Microstrip Antenna Array Fed by a Low-Loss Gap-Waveguide Feed Network," *IEEE Transactions on Antennas and Propagation*, Vol. 66, No. 8, pp. 4359-4363, 2018
11. Z. W. Yu and G. M. Wang, "A Broadband Planar Monopulse Antenna Array of C-Band," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, pp. 1325-1328, 2009
12. C. A. Balanis, "Antenna Theory: Analysis Design," 3rd Edition, John Wiley & Sons, New York, 2005
13. F. W. Yao, X. B. Xuan, Y. Y. Liu, and Y. B. Shang "A Novel Compact Microstrip Slot Antenna with Spirals," in *Proceedings of 2012th International Symposium on Antenna Propagation and EM Theory Conference*, pp. 395-397, 2012

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