

## Compact Ku-band monopulse microstrip stacked patch array antenna with hybrid power divider system

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Received 9 Apr. 2024; Revised 13 Jun. 2025; Accepted 10 Aug. 2025; Published 25 Aug. 2025.

DOI: <https://doi.org/10.54939/1859-1043.j.mst.105.2025.44-51>

### ABSTRACT

*This article will present an array antenna system with a compact size (diameter 190 mm) for a monopulse tracking application working in the Ku band, suitable for placement airborne where there is not much space. The antenna system consists of a monopulse comparator, a power divider system, and four subarray antennas. The monopulse comparator and part of the hybrid power divider are designed on the rectangular dielectric waveguide (RDW). The other part of the power divider and antenna element array is designed on the PCB substrate. The two parts of the power divider system are connected to each other through coaxial cables. Simulation results of the antenna system are obtained as follows: impedance bandwidth (VSWR < 1.8) is about 9%; SLL of the radiation pattern of an array antenna using an unequal power divider system with Taylor distribution (SLL = -20 dB, n = 4) at full range frequency is less than -20 dB. The realized gain of the sum beam is 28 dBi at the center frequency, while the zero depth of the difference beam is better than 20 dB. The excellent features of the proposed design make it a good candidate for two-dimensional monopulse tracking applications.*

**Keywords:** Array antenna; Monopulse comparator; Dielectric rectangular waveguide; Unequal power divider; Microstrip stacked patch.

### 1. INTRODUCTION

Monopulse array antennas are widely used in high-resolution angle tracking applications [1]. It is developed by different types of technology on many different frequency bands [2 - 8], such as a monopulse antenna array consisting of 16 by 16 circularly polarized radiating cavities fed by a corporate waveguide network with an amplitude taper at W-band with up to 10% bandwidth (VSWR < 2) [2]. However, the use of a uniform corporate power divider, as mentioned in the paper, results in a sidelobe level of only about -13 dB. Therefore, the paper proposes using a non-uniform power distribution (specifically, Taylor distribution) to reduce the antenna's sidelobe level; a 28 × 28 circular slotted waveguide monopulse antenna array Ka-band with 1.48% bandwidth (return loss less than -20 dB) and sidelobe level less than -25 dB [3]. However, the paper presents a standing-wave slot antenna design in which the slots are positioned at intervals of one-quarter of the waveguide wavelength. This inherently limits the antenna's bandwidth expansion. Therefore, the paper proposes several solutions, including using a corporate waveguide power divider loaded with dielectric material and partially implementing the power division network using microstrip lines; a series feed monopulse microstrip antenna array X-band feed with 0.43% bandwidth (VSWR < 1.8) and sidelobe less than -15 dB [4]. However, the paper presents a patch antenna design with a series feed power divider, which limits the bandwidth. A highly-efficient monopulse antenna system is proposed for a radar tracking system application with VSWR < 1.5, which is 12.9% in the Ku band, and SLL < 14 dB, and it's made by a 3-D metal-direct-printing technique [5]. However, similar to reference [2], this paper uses a uniform corporate power divider, resulting in a sidelobe level of only around -13 dB; The 112-elements monopulse array antenna at X-band with comparator and full corporate feed network including waveguide and microstrip divider with impedance bandwidth ( $S_{ii} \leq -12$  dB) is up to 12% with the isolations better than 20 dB. The

maximum gain of the sum beam is 28.7 dBi, while the null depths of the difference patterns are better than 24 dB [6]. However, similar to reference [2, 5], this paper uses a uniform corporate power divider, resulting in a sidelobe level of only around -13 dB. The paper presents a high-gain, low-sidelobe monopulse microstrip array antenna for Ku-band FMCW radar. It features a 16×32 series-fed patch array and a waveguide-fed monopulse comparator using a WR51 magic tee. The antenna is fabricated with PCB and machining techniques, ensuring precise alignment. Measurements at 17 GHz show 32.5 dBi gain, -25 dB sidelobe level, and -27 dB null depth [7]. The paper presents a Ku-band microstrip monopulse array with 32% efficiency, built on a single-layer low-loss dielectric. The antenna demonstrates good performance, achieving 33 dBi gain and 32% efficiency [8]. However, the paper [7, 8] presents a patch antenna design with a series feed power divider, which limits the bandwidth.

In this paper, a monopulse array antenna at Ku-band using a stacked patch antenna as an element with an unequal power divider achieves sidelobe levels less than -20 dB in a bandwidth of about 9% (VSWR<1.8). The research results of stacked patch antenna elements, unequal power divider, monopulse comparator, and overall array antenna system are presented later in the paper.

## 2. STRUCTURE OF THE ANTENNA ARRAY SYSTEM

The overview structure of the antenna array system (figure 1) includes the following parts: monopulse comparator, unequal power divider system on two planes, and antenna array (four subarrays A, B, C, D).

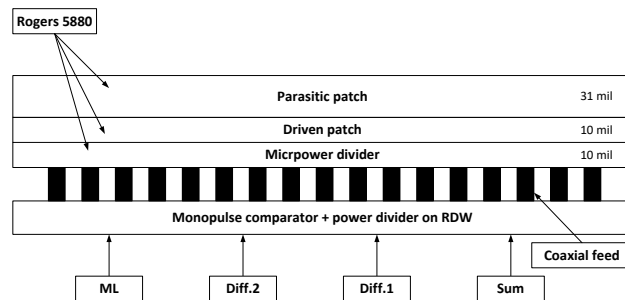


Figure 1. Structure of the antenna array system.

### 2.1. Antenna elements

In the paper, a stacked patch is used as an element of the antenna array to increase the bandwidth of the antenna array. The structure of the element consists of a driven patch and a parasitic patch. The structure of the element is shown in figure 2.

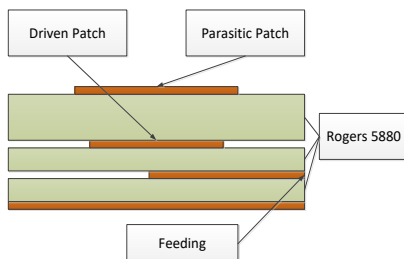


Figure 2. Structure of the stacked patch elements.

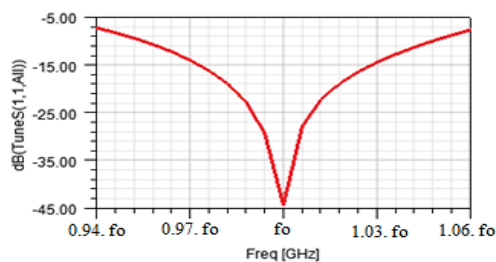


Figure 3. Simulation results of the reflection coefficient of the infinitive stacked patch array (unit cell).

To optimize the bandwidth of the antenna array, the specific size of each element will be individually optimized to accommodate the power divider (referred to later), resulting in different sizes of the elements.

In this paper, infinite array antennas are studied using the finite element method. Specifically, we know the array antennas consist of identical elements and are arranged at equal distances, that is, periodic. Because of this periodic feature, by using two Master/Slave and port Floquet to describe the boundary conditions of an element, we will get results equivalent to the results of an array antenna of infinite size.

Figure 3 shows the simulation results of the reflection coefficient of the infinite array antenna with stacked patch elements. With a reflection coefficient less than -15 dB, the frequency bandwidth of the infinity array reaches about 6% (Ku band).

**2.2. Monopulse comparator**

The design of the monopulse comparator on the PCB used the substrate of RT/duroid 5880 ( $\epsilon_r = 2.2$ ) with a thickness of 31 mils (figure 4). The monopulse comparator consists of one sum port and two difference ports.

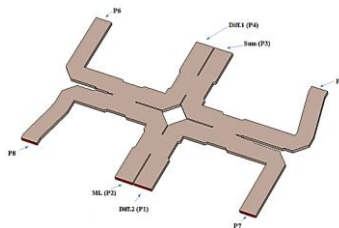


Figure 4. Structure of the monopulse comparator.

The simulation results of the study of the monopulse comparator's characteristics, such as VSWR, transmission coefficient, and phase response, are shown in figures 5, 6, and 7.

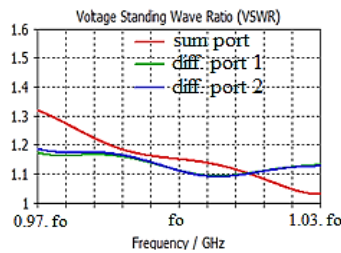


Figure 5. The simulation results of the VSWR of the monopulse comparator.

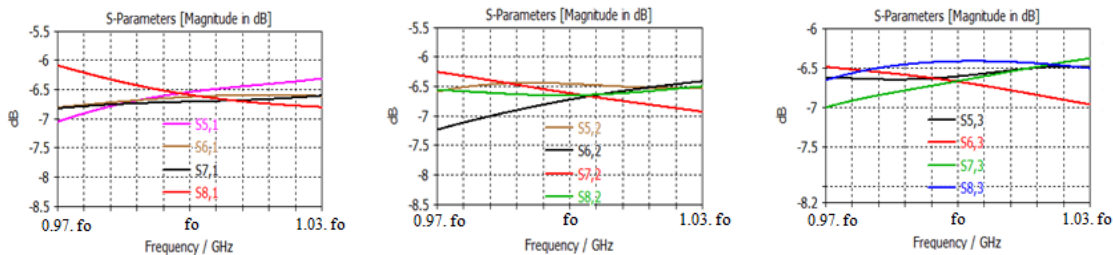


Figure 6. The simulation results of the transmission coefficient of the monopulse comparator.

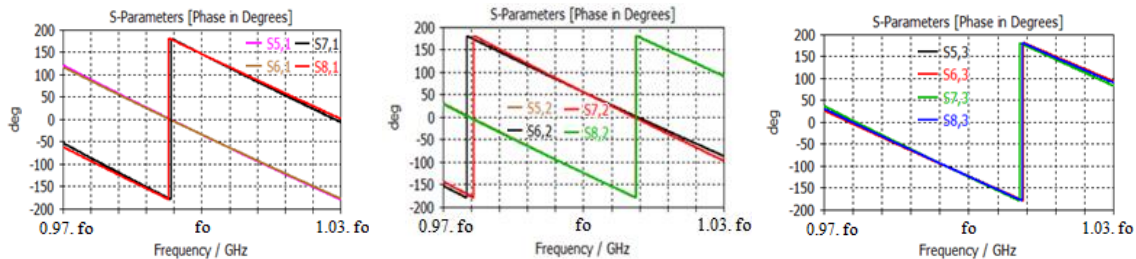
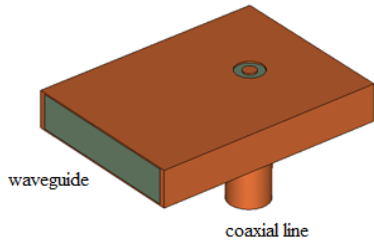


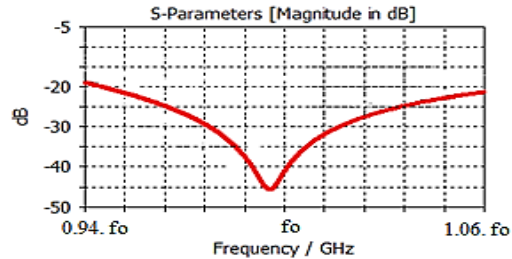
Figure 7. The simulation results of the phase response of the monopulse comparator.

### 2.3. A coaxial-to-waveguide adapter for monopulse comparator and power divider on RDW

The input of the monopulse comparator and the output of the power divider on the RDW are fed from the coaxial line. A coaxial-to-waveguide adapter is designed as shown in figure 8. The simulated reflection coefficient of the adapter is shown in figure 9.



**Figure 8.** Structure of the coaxial-to-waveguide adapter.



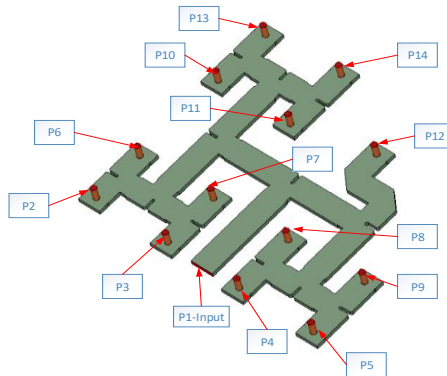
**Figure 9.** The simulation results of the reflection coefficient of the adapter.

### 2.4. Power divider system

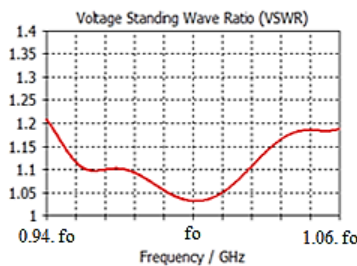
An uneven power distribution method for each element can be used to reduce the sidelobe level [9, 10]. Specifically, the paper is using the unequal distribution of power according to the Taylor distribution  $SLL = -20$  dB,  $n = 4$ .

In the paper, the power divider consists of two parts. The first part is designed on RDW with the substrate of RT/duroid 5880 (thickness of 62 mils) from T-junctions (figure 10), while the second part is designed on a corporate microstrip feed network with PCB substrate RT/duroid 5880 (thickness of 10 mils).

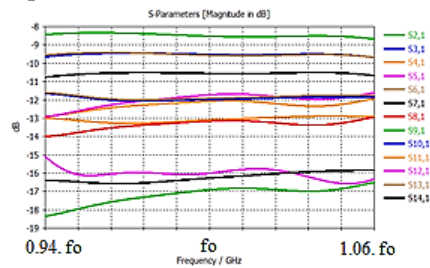
Figure 11 and 12 respectively show the results obtained for the Taylor unequal power divider as VSWR and power level. Notice that the power divider VSWR is less than 1.2 in the frequency range  $0.94f_0 - 1.06f_0$  (Ku band) and the power levels of the ports gradually decrease by Taylor distribution with  $SLL = -20$  dB,  $n = 4$ .



**Figure 10.** Structure of the unequal power divider on RDW.



**Figure 11.** The simulation results of the return loss of the unequal power divider.



**Figure 12.** The simulation results of the transmission coefficient of the unequal power divider.

A microstrip power divider is designed and optimized when combined with 2 or 4 patch antenna elements, as shown in figure 13. Optimizing each element of the antenna array instead of all antenna elements being designed the same will help the antenna system be more optimal in terms of VSWR index. The reflection coefficient of the 2x2 and 2x1 subarrays is shown in figure 14.

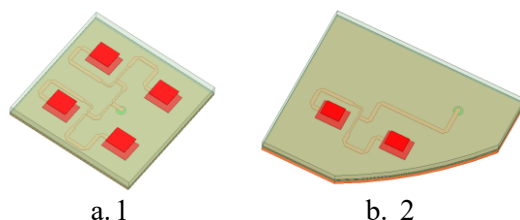


Figure 13. Structure of the microstrip power divider 2x2 and 2x1 elements.

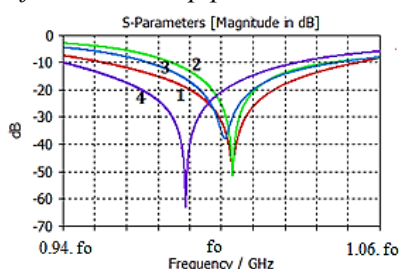


Figure 14. Reflection coefficient of the 2x2 and 2x1 subarrays.

### 3. SIMULATION RESULTS OF THE ARRAY ANTENNA SYSTEM

The overall combined structure of the array antenna is shown in figure 15 with dimensions: diameter: 190 mm; height: 10 mm.

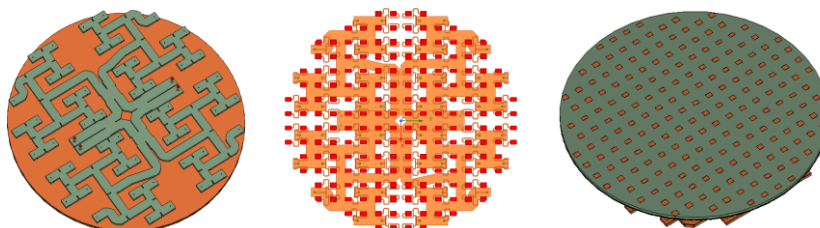


Figure 15. Structure of the array antenna.

The simulated reflection coefficient and VSWRs of the sum and two difference channels are shown in figure 16. Simulation results show that the impedance bandwidth is about 9% for VSWR < 1.8 at all ports for the array antenna. The isolation coefficient between the total and difference ports is shown in figure 17. According to the results, we see that the isolation coefficient between the ports is < - 20 dB.

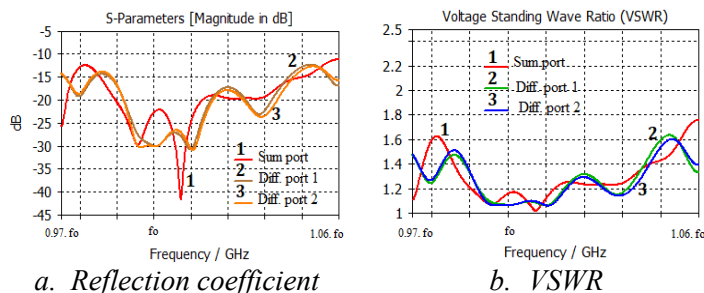
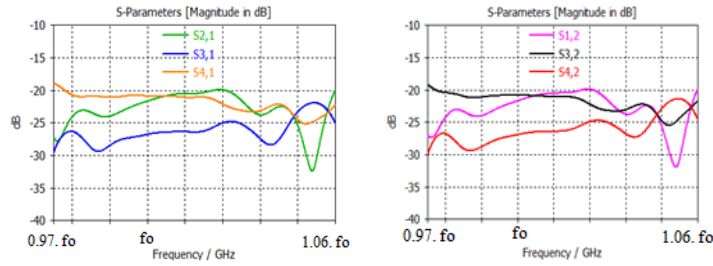
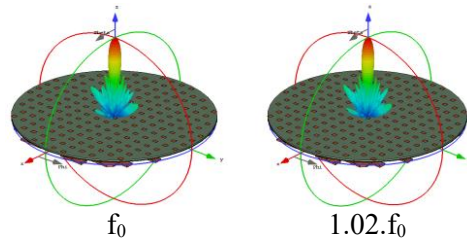


Figure 16. The simulation results of the monopulse array antenna for the sum and difference ports.

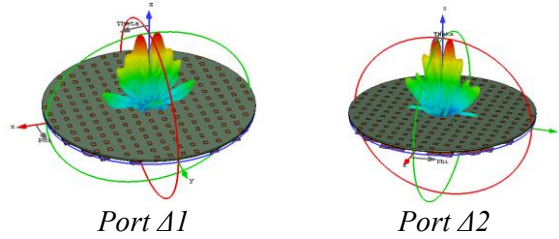


**Figure 17.** The isolation coefficient between the ports of the antenna system.

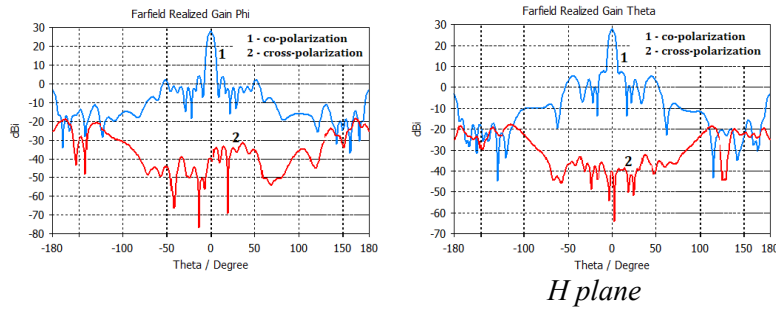
The sum and difference radiation patterns of the antenna array are shown in figures 18-22. The dependence of SLL and realized gain on frequency is shown in tables 1 and 2.



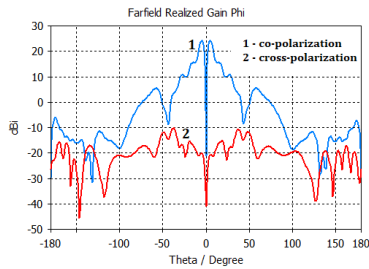
**Figure 18.** The simulated results of the 3D radiation patterns for the sum port.



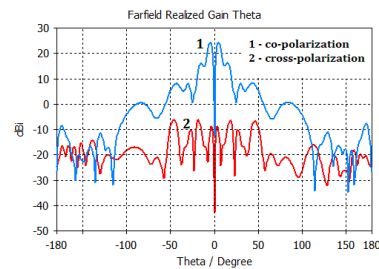
**Figure 19.** The simulated results of the 3D radiation patterns for the center frequency  $f_0$ .



**Figure 20.** The simulated results of the radiation pattern for the sum port in frequency  $f_0$ .



**Figure 21.** The simulated results of the radiation pattern for the difference port 1 in frequency  $f_0$ .



**Figure 22.** The simulated results of the radiation pattern for the difference port 2 in frequency  $f_0$ .

**Table 1.** SLL of the sum radiation pattern.

Number	Frequency	H plane (dB)	E plane (dB)
1	$0.97.f_0$	-23	-18
2	$0.98.f_0$	-21.6	-21.5
3	$0.99.f_0$	-22.3	-20
4	$f_0$	-23.5	-20.3
5	$1.01.f_0$	-24	-20.2
6	$1.02.f_0$	-23.8	-22.1
7	$1.03.f_0$	-23.4	-20

**Table 2.** Gain of the sum radiation pattern.

Number	Frequency	Realized Gain (dBi)
1	$0.97.f_0$	27.5
2	$0.98.f_0$	27.5
3	$0.99.f_0$	27.8
4	$f_0$	27.9
5	$1.01.f_0$	28
6	$1.02.f_0$	28.1
7	$1.03.f_0$	27.8

**Table 3.** Comparison with some previous designs of monopulse antennas.

Reference	Frequency band	Percentage bandwidth,%	Realized Gain for center frequency, dBi	SLL for center frequency, dB	Type of antenna	Type of power divider
[2]	W band	10%	31dBi	-18dB	Monopulse cavity slotted array	Corporate feed
[3]	Ka band	1.48%	-	-28dB	Monopulse waveguide slotted array	Series feed
[4]	X band	0.43%	20dBi	-15dB	Monopulse patch array	Series feed
[5]	Ku band	12.9%	31.5dBi	-13dB	Monopulse cavity slotted array	Corporate feed
[6]	X band	12%	28.7dBi	-13dB	Monopulse patch array	Corporate feed
[7]	Ku band	1.17%	32.5dBi	-25dB	Monopulse patch array	Series feed
[8]	Ku band	0.5%	33dBi	-18dB	Monopulse patch array	Series feed
This work	Ku band	9%	28dBi	-20dB	Monopulse stacked patch array	Hybrid corporate (RDW and microstrip line)

#### 4. CONCLUSIONS

This paper presents the structure of a compact monopulse array antenna for target tracking applications, suitable for places with a small space. The stacked patch monopulse antenna array at Ku-band with a corporate unequal power divider is presented. The impedance bandwidth of the antenna is about 9% for  $VSWR < 1.8$ . Using an unequal power divider has reduced the SLL below  $-20$  dB over the frequency range. Meanwhile, the realized gain of the antenna is greater than 27.5 dBi.

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#### TÓM TẮT

##### Ăng-ten mảng vi dải nhiều lớp nhỏ gọn chế độ đơn xung băng tần Ku sử dụng hệ thống chia công suất lai

Bài viết này sẽ trình bày một hệ thống Ăng ten mảng có kích thước nhỏ gọn (đường kính 190 mm) cho ứng dụng theo dõi đơn xung hoạt động trong băng tần Ku, phù hợp để lắp trên không nơi không có nhiều không gian. Hệ thống Ăng ten bao gồm bộ tổ hợp xung đơn, hệ thống chia công suất và bốn Ăng ten mảng con. Bộ tổ hợp xung đơn và một phần của bộ chia công suất lai được thiết kế trên ống dẫn sóng chứa chất điện môi hình chữ nhật. Phần còn lại của bộ chia công suất và mảng phần tử Ăng ten được thiết kế trên mạch vi dải. Hai phần của hệ thống chia công suất được kết nối với nhau thông qua cáp đồng trục. Kết quả mô phỏng của hệ thống Ăng ten thu được như sau: băng thông trở kháng ( $VSWR < 1,6$ ) khoảng 9%; SLL của mẫu bức xạ của anten mảng sử dụng hệ thống chia công suất không đồng đều với phân phối Taylor ( $SLL = -20$  dB,  $n = 4$ ) ở tần số toàn dải nhỏ hơn  $-20$  dB. Độ lợi thực tế của chùm tổng là 28 dBi ở tần số trung tâm, trong khi độ sâu của búp sóng hiệu 20 dB. Các tính năng của sản phẩm trong thiết kế phù hợp cho các ứng dụng theo dõi đơn xung trên 2 kênh góc tà và góc phương vị.

**Từ khóa:** Ăng ten mảng; Bộ tổ hợp đơn xung; Ống dẫn sóng hình chữ nhật chứa chất điện môi; Bộ chia công suất không đồng đều; Ăng ten vi dải nhiều lớp.