Using Hybrid Ring Coupler to Form Butler Matrix of Switched Beam Antenna Array System for Wireless Communication Products

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Abstract

Switched beam Antenna array is a kind of smart antenna system, wherein an appropriate radiation pattern to transmit and receive signals can be selected. The structure switched beam antenna array system implemented in this paper contains an antenna array and a feed network composed by the 4*4 Butler matrix. Here, one wavelength of hybrid ring coupler will replace the original Butler matrix structures formed by branches of coupling devices, to undergo implementations and measurements. Because hybrid ring couplers may replace Butler matrix, its allocation of positions along the circuit is quicker. On the antenna array implementation, this paper uses four omni-direction antennas with distances of half a wavelength from each other to form an antenna array with linear arrangement. This coordinates with the hybrid ring Butler matrix feed network. The measured four beam directions obtained from realistic implementations matches the simulated ideal omni-directional radiation pattern of the antenna array. Hence, the antenna array implementation method this paper proposes can serve as a reference for future applications of switched beam systems on wireless communication products.

Key words：Antenna array, Hybrid ring coupler, Butler matrix.

1. Introduction

The advantage of using switched beam antenna array system is that it can be established and expanded at a lower expense. This realistically improves the quality of communication and effectively increases the service scope. The antenna array provides the main beam that can overcome the interference caused by excessively multiple routes, and can break through the binding of omni-directional or directional antenna at the radiation site, achieving power conservation. Utilizing the space and breaking this space into multiple incoming mechanisms causes users in the same cell to communicate simultaneously, increasing the capacity of communication systems[1]. The realization of switched beam antenna array systems in hardware includes two parts. The first part is the formation of the antenna array. Second part is the phase difference control circuit. The combination of these two parts forms the entry signal for that uses the lower end. Through the phase difference matrix network, which is also the Butler matrix, similar phase differences are created between antennas. This causes antenna array to form main beams of fixed angles. [2]。

On the aspect of antenna array formation, an adequate radiation pattern [3] is made by assigning an array factor to an element radiation pattern. Here we assume that the element radiation pattern is equal to 1. This is the same as using omni-directional antenna to form an antenna array through a straight line, linear antenna array permutation method. Hence, the obtained array factor is:

$$F(\phi) = \frac{\sin N \cdot \frac{\phi}{2}}{N \cdot \sin \frac{\phi}{2}}$$

The antenna has the denominator of four, i.e. N=4. Figure 1(a) shows that at the angle formed at the ϕ axis, the beam forms the main beam and the amplitude of the adjacent beam; hence there is maximum value when $\phi = 0$. From $\phi = \beta d \cos\theta + \alpha$, it can be known that if the radiation pattern of antenna array main beam is to be changed, adjusting the phase difference α and the distance between the element antennas d may change the direction of the beam. 4*4 Butler matrix is formed by four directional coupling devices plus two microwave phase inverters. The traditional coupling devices are usually made by combining branch coupling devices. In this paper, we improved this by using hybrid ring couplers to realize the 4*4 Butler matrix.

2. Implementation and Measurements

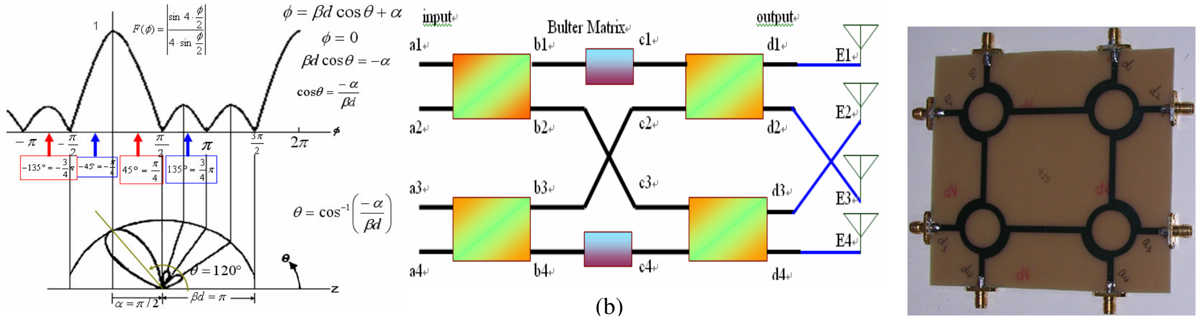
In making a singular 3λ/2 hybrid ring coupler [4], work frequency, bandwidth, phase angle, and power can all be precisely shown based on the designed values. However, when microwave couplers are combined and form the 4*4 Butler matrix, the change in phase is already not the designed angle. With this problem of implementation, analysis concludes that the symmetry of negative space caused the two directional reflection indices to lose balance, and thereby causing the changes in phase. In order to prove this concept, simulated one wavelength, two wavelengths, four wavelengths, five wavelengths, etc, were made in succession and partially tested and measured. Finally, one wavelength hybrid ring coupler was implemented and 4*4 hybrid ring Butler matrix was realized. Also, the three advantages to using this matrix were obtained. The specifications of the implementation use unlicensed 2.4GHz band (2.4GHz~2.4835GHz). The designed central frequency is 2.4415GHz，bandwidth is 83.5MHz.

Figure 2(a) shows the hybrid ring coupler. The problem in input port 1 and output port 2 and 3 lies in the inequality of output frequency. Hence, after adjusting the width of every arc, simulation software can be used to analyze and calculate frequency allocation resistance. Figure 2(b) shows the use of network analyzer to measure input port1 and output port2. The best work point can be seen on the frequency 2.42GHz. S_{11} Smith chart prevents the nearing to the original point 50Ω. S_{11} at 2.42GHz has -49.27dB. the insertion loss of S_{21} is approximately -3.5dB. Figure 2(c) is the input port 1 and output port 3. From the index it can be observed that the best work can be seen in frequency 2.44GHz. S_{11}Smith chart prevents the nearing to the original point 50Ω. S_{11} at 2.44GHz has -47.59dB, S_{31} insertion loss is approximately -3.5dB. Figure 1(c) is the actual photo of a hybrid ring Butler matrix. Figure 1(b) shows the input output relationship model of the Butler matrix. From the figure's index positioning relationship, the input a1、a2、a3、a4and the output d1、d2、d3、d4, and the connecting beams E1、E2、E3、E4 can be clearly seen. The measured phase value arrangement is shown in Table 1. From the four-base antenna forming antenna array, the measured central frequency is set at 2.4415GHz. The distance between antennas is 0.5λ or 6.2cm. Inputting a1 to the Butler matrix and outputting four base antennas, a phase difference of -45° occurs between antennas. Figure 3(a) shows the measured radiation pattern that is obtained from the four base antennas and Butler matrix a1 input. The gain obtained after comparing this with the standard antenna is 6.363dB. Inputting a2, the phase difference between antennas is 135°.

The radiation pattern is shown in Figure 3(b). The antenna gain is 4.836dB. Inputting a3, the phase difference between antennas is -135°. The radiation pattern can be seen in Figure 3(c). The antenna gain is 3.896dB. Inputting a4, the phase difference between antennas is 45°. The radiation pattern is shown in Figure 3(d). The antenna gain is 6.341dB。The upper half portion of Figure 3(e) shows the ideal simulation. The lower half shows the combination of actual measurement figures (a)(b)(c)(d) into one. From a certain angle, the simulated and the actual measurements are almost the same. On the aspect of size, one division in the axis of the simulated figure is equal to -10dB. While on the other hand, one division in the axis of the actual figure is equal to -5dB. Relatively speaking, the simulated and the actual are almost similar.

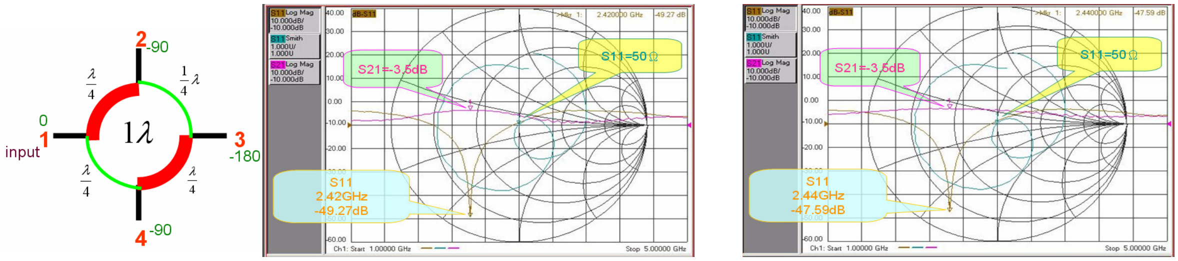
3. Conclusion

In this paper, a 4*4 hybrid ring Butler matrix is proposed. The 4*4 hybrid ring Butler matrix formed from the one wavelength hybrid ring coupler has three advantages over the original Butler matrix formed from branched couplers: First, the single hybrid ring coupler has a round and curly geometry area that is smaller than the branched matrix. Second, the 90 degree space difference between the transmission waves from the hybrid ring coupler output ports is the smallest from the perspective of interfering couplers. Third, the middle of the hybrid ring Butler matrix can be used to make circuits, increasing the circuit area that is capitalized on. The results of the design and actual experiments of this paper are almost similar with the theoretical beam radiation pattern. It can be served as a reference for applications of switched beam systems on wireless communication products.



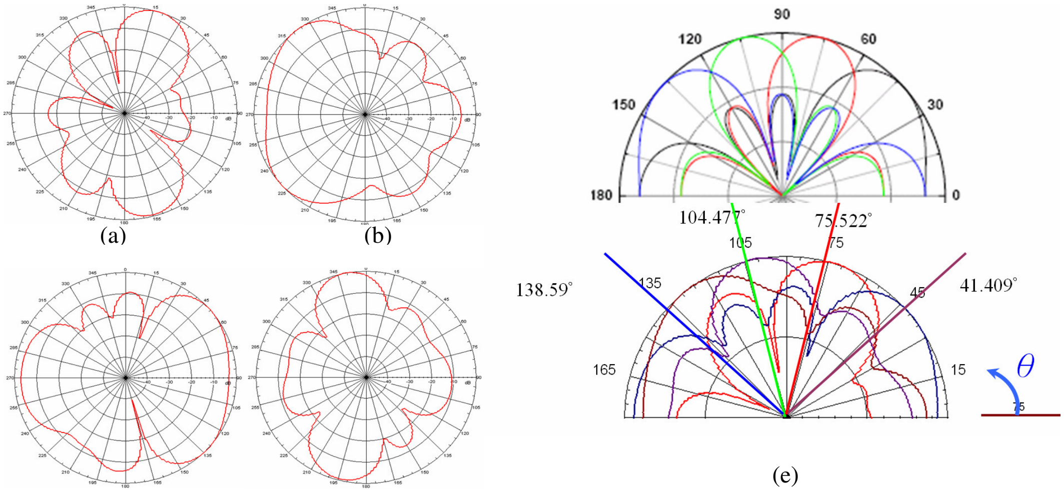
(a) (b) (c)

Figure 1: (a)N=4 Array index relationship model between ϕ angle and θ angle. (b)Relationship model of Butler matrix input and output. (c)Photo of hybrid ring Butler matrix



(a) (b) (c)

Figure 2: (a)one wavelength hybrid ring coupler schematic diagram. (b) Measurement model for port 1 port 2 on S11and S21. (c) Measurement model for port 1 port3 on S11 and S31



(a) (b) (c) (d) (e)

Figure 3: (a)Radiation pattern from input a1 with -45° phase difference. (b)Radiation pattern from input a2 with 135° phase difference. (c)Radiation pattern from input a3 with -135° phase difference. (d)Radiation pattern from input a4 with 45° phase difference. (e)Comparative models for simulated and actual measurements

Table 1: Phase Arrangement model

a1 (-45˚)	E(phase)	difference angle(˚)	a3 (-135˚)	E(phase)	difference angle(˚)
E1	-163.93	-41.2	E1	152.99	-135.459
E2	154.65	-48.1	E2	17.531	-134.211
E3	106.55	-41.672	E3	-116.68	-135.68
E4	64.878		E4	107.64	
a2 (135˚)	E(phase)	difference angle(˚)	a4 (45˚)	E(phase)	difference angle(˚)
E1	106.39	138.18	E1	60.94	45.04
E2	-115.43	132.446	E2	105.98	46.11
E3	170.16	138.034	E3	152.09	44.35
E4	155.05		E4	-163.56	

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