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By Guohui YANG

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A Miniaturized 4×4 Butler Matrix Using Distributed capacitors in the Quasi-Arbitrary Phase-Difference Hybrid Coupler

Haikang Ji
Nanjing University of Aeronautics and Astronautics
NanJing, China
975217064@qq.com

Yang Yang
Nanjing University of Aeronautics and Astronautics
NanJing, China
eeyy@nuaa.edu.cn

Xiaoxiang He
Nanjing University of Aeronautics and Astronautics
NanJing, China
eexxhe@nuaa.edu.cn

Beibei Ma
Nanjing University of Aeronautics and Astronautics
NanJing, China
bbma0115@nuaa.edu.cn

Zhenyu Shen
Nanjing University of Aeronautics and Astronautics
NanJing, China
eeshenzy@nuaa.edu.cn

Yin Chen
Nanjing University of Aeronautics and Astronautics
NanJing, China
ttttomchen@foxmail.com

Yiwei Chen
Nanjing University of Aeronautics and Astronautics
NanJing, China
yiweichen@nuaa.edu.cn

***Abstract*-This communication describes a miniaturized 4×4 Butler Matrix Using Distributed capacitors in the Quasi-Arbitrary Phase-Difference Hybrid Coupler. First, A traditional branch-line coupler with any phase difference can be calculated the impedance and phase of each short side. next, a transmission line can be replaced by a high impedance transmission line and parallel capacitors, meanwhile. To miniaturize the circuit, all distributed capacitances are placed inside the branch coupler. Based on this compact branch line coupler configuration, a miniaturized 4 × 4 Butler matrix requires standalone phase shifters and crossovers eliminated. A distributed capacitive branch coupler with arbitrary phase difference is proposed to replace the traditional branch coupler. Through the miniaturized design of branch couplers and the elimination of phase shifters and crossover junctions, the design of the butler matrix is 66% smaller than the traditional butler matrix design proceedings.**

***Keywords* – distributed capacitors, Butler, quasi-arbitrary phase-difference, coupler.**

I. INTRODUCTION

Research on the Miniaturization of Multi-beam Feeder Networks has been a lot of attention in the past few decades It can greatly reduce the area of the RF front-end. In existing research it has several research methods in butler matrix to miniaturize size. Various compact butler structures[1], [2],had been proposed. Based on the size of conventional Butler matrices is large. The asymmetrical structure provides fairly flexible phase outputs are proposed. For example, in [3]Wi-Fi frequency(2.45GHz) uses single-pole double-throw (SPDT) switches added to select the proper constant phase shifts,the oversize of structure is reduced by 22%. By replacing the traditional quadrature coupler with an arbitrary phase difference coupler[4], the output port of the proposed butler matrix can be relatively flexible, and the redundant microstrip line that replaces the phase difference can be removed.

In this paper, a novel miniaturized arbitrary phase difference coupler is implemented, and the phase difference is generated by distributed capacitance. Firstly, the miniaturization processing of quadrature coupler based on distributed capacitance is proposed by replacing the original impedance line equivalently with a high impedance transmission line and capacitors, and all distributed capacitors are implemented in the inner area of the branch line coupler. Secondly, the coupler with arbitrary phase difference output is finally realized by analyzing different distributed capacitances.

II. DESIGN OF BUTLER MATRIX

In this paper, the crossover and the phase shifter are removed, the closed-loop connection of the coupler of any phase reduces the area of the Butler matrix by a lot of wiring resources that resulted in a significant reduction in the size. Fig. 1 shows the Butler matrix, with four input ports 1-4, and four output ports 5-8. The Butler matrix consists of two 90° distributed capacitors compact hybrid couplers and two 135°/45° distributed capacitors phase-difference hybrid couplers are shown in Fig. 2. Loading lines are a practical way to miniaturize transmission line circuit. From the results in [5] , the design with mixed distributed and lumped distributed elements, the equivalent circuits was performed carefully in order to obtain a sufficient design area.

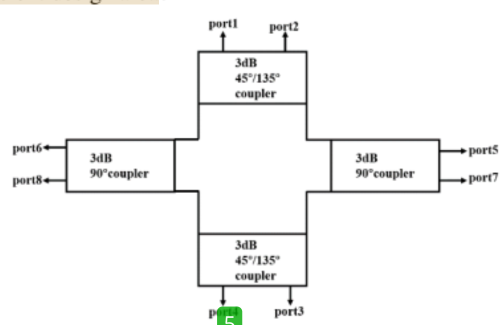
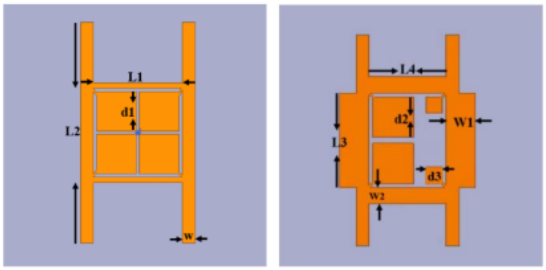


Figure 1. Schematic of the proposed Butler matrix.

The proposed coupler structure is fabricated on a substrate with a dielectric, constant εr = 2.55, loss tangent δ = 0.0029, thickness h = 0.8 mm, The center frequency of the coupler is 2.4GHz.



(a) (b)

Figure 2. (a) 90° hybrid couplers. (b) 135° /45° hybrid couplers.

The matrix formula can be known from[5], so that the following equivalent circuit parameters can be deduced. Equivalent to(1)(2)(3).

$$jB_{o1} = j\tan\,\theta_{o1}/Z_{o1} \tag{1}$$

$$B_{o1} = \frac{\cos\,\theta_S - \cos\,\theta}{Z_C \sin\,\theta} \tag{2}$$

$$Z_S = \frac{Z_C \sin\,\theta}{\sin\theta_S} \tag{3}$$

Here B_{o1} is the distributed capacitance value, θ_{o1} and Z_{o1} are the phase and impedance of the open stub at both ends, θ_S is the phase of the series transmission line, θ is the phase of the original transmission line, Z_C is the impedance of the original transmission line, and Z_S is the impedance of the series transmission line. The distributed capacitance is calculated by the above formula. The physical length of distributed capacitors can we know from[6]. Equivalent to(4).

$$\begin{aligned} B_{o1} &= C_1 + C_2 \\ &= \frac{\cos\theta_{1E}}{\omega Z_{1A}} + \frac{\cos\theta_{2E}}{\omega Z_{2A}} \\ &= \frac{\lambda_{e,1E}}{2\pi c}\frac{\cos\left(\frac{2\pi\ell_{1E}}{\lambda_{e,1E}}\right)}{Z_{1A}} + \frac{\lambda_{e,2E}}{2\pi c}\frac{\cos\left(\frac{2\pi\ell_{2E}}{\lambda_{e,2E}}\right)}{Z_{2A}} \end{aligned} \tag{4}$$

that where c is the speed of light and $\lambda_{e,1E}$, $\lambda_{e,2E}$, $\lambda_{e,3E}$ are the effective wavelengths at the center frequency. and $\lambda_{e,1E}$ $\lambda_{e,2E}$ are the side lengths of the internal distributed capacitors. Z_{1A} , Z_{2A} , and Z_{3A} are the impedance values of different transmission lines, respectively. All distributed capacitors have the same value, where $\lambda_{e,1E} = \lambda_{e,2E.}$ After calculating the formula, use the electromagnetic simulation software HFSS to carry out simulation optimization, and obtain the maximum size parameters after fine-tuning. L1=13.3mm, L2=12.8mm, W=1.9mm, d1=6.2mm, L3=16mm, L4=13mm, W1=5.2mm, W2=3.2mm, d2=7.1mm, d3=3.2mm.

The above-mentioned couplers are sequentially closed-loop connected through the schematic mechanism .Since there is no need for a crossover structure, the size is greatly reduced, as is shown in Fig. 3.

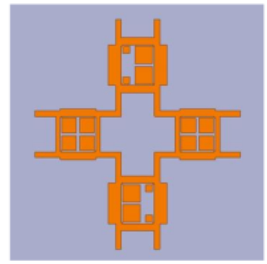
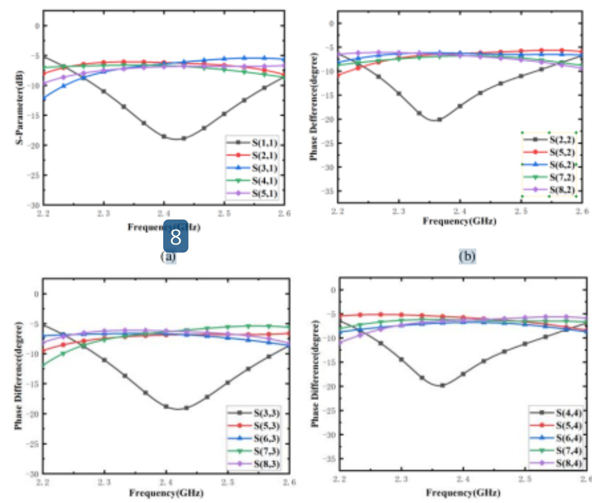


Figure 3. Structure of 4×4 Butler matrix

III. RESULT

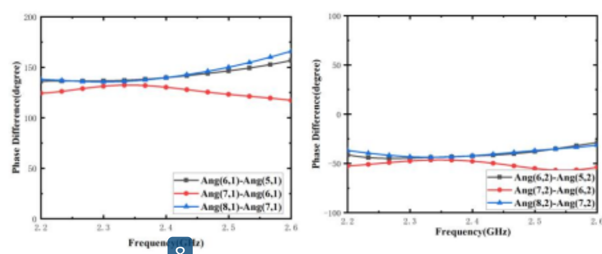
The Butler matrix can be easily formed by connecting couplers with short microstrip lines and feeding through the ports, the s-parameter result graph shown in Fig. 4. can be obtained, the measured S-parameters are less than -10dB from (2.3-2.6GHz), the insertion loss is 6.9±1dB. Since the signal passes through the two-layer coupler, the insertion loss of the two couplers is 3dB drive.



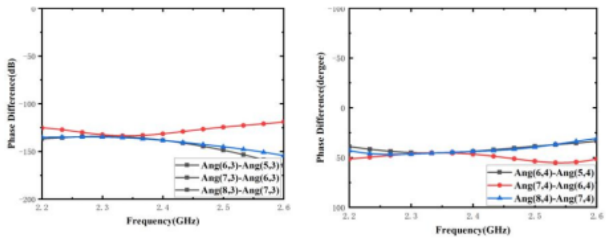
(a) (b) (c) (d)

Figure 4. Simulated results of proposed Butler matrix. (a) S-parameter of port1 is excited (b) S-parameter of port2 is excited (c) S-parameter of port3 is excited (d) S-parameter of port4 is excited.

The phase differences of feeding at each port through the simulation software are 135°±9°, -45±10°, -135±8°, and 45°±7°, respectively. As shown in Fig. 5. below.



(a) (b)



(c) (d)

Figure 5. Simulated results of proposed Butler matrix. (a) phase-difference of port1 is excited (b) phase-difference of port2 is excited (c) phase-difference of port3 is excited (d) phase-difference of port4 is excited.

IV. Conclusion

The design in this paper is different from the traditional butler matrix, a new design is proposed, the proposed coupler can achieve arbitrary phase difference, and the corresponding Butler matrix can be easily constructed by connecting the couplers with short microstrip lines, to achieve the purpose of miniaturization, the realized butler matrix meets the requirements of s-parameters between 2.2-2.6GHz. Through the input of different ports, realize the phase difference of ±135° and ±45°.

References

[1] E. Vandelle, D. H. N. Bui, T. -P. Vuong, G. Ardila, K. Wu and S. Hemour, "Harvesting Ambient RF Energy Efficiently With Optimal Angular Coverage," in *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 3, pp. 1862-1873, March 2019, doi: 10.1109/TAP.2018.2888957.

[2] J. M. Wen, C. K. Wang, W. Hong, Y. M. Pan and S. Y. Zheng, "A Wideband Switched-Beam Antenna Array Fed by Compact Single-Layer Butler Matrix," in *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 8, pp. 5130-5135, Aug. 2021, doi: 10.1109/TAP.2021.3060040.

[3] A. Tajik, A. Shafiei Alavijeh and M. Fakharzadeh, "Asymmetrical 4×4 Butler Matrix and its Application for Single Layer 8×8 Butler Matrix," in *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 8, pp. 5372-5379, Aug. 2019, doi: 10.1109/TAP.2019.2916695.

[4] H. Ren, B. Arigong, M. Zhou, J. Ding and H. Zhang, "A Novel Design of 4×4 Butler Matrix With Relatively Flexible Phase Differences," in *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1277-1280, 2016, doi: 10.1109/LAWP.2015.2504719.

[5] S. Jung, R. Negra and F. M. Ghannouchi, "A Design Methodology for Miniaturized 3-dB Branch-Line Hybrid Couplers Using Distributed Capacitors Printed in the Inner Area," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 56, no. 12, pp. 2950-2953, Dec. 2008, doi: 10.1109/TMTT.2008.2007323.

[6] Young-Hoon Chun and Jia-Sheng Hong, "Compact wide-band branch-line hybrids," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 2, pp. 704-709, Feb. 2006, doi: 10.1109/TMTT.2005.862657.

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1	Jia Min Wen, Chuang Kai Wang, Wonbin Hong, Yong Mei Pan, Shao Yong Zheng. "A Wideband Switched-Beam Antenna Array Fed by Compact Single-Layer Butler Matrix", IEEE Transactions on Antennas and Propagation, 2021 Crossref	76 words — 6%
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7	Sung-Chan Jung. "A Design Methodology for Miniaturized 3-dB Branch-Line Hybrid Couplers Using Distributed Capacitors Printed in the Inner Area", IEEE Transactions on Microwave Theory and Techniques, 2008 Crossref	20 words — 2%
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14 Mekala Harinath Reddy, David Siddle, D. Sheela. "Design and implementation of a beam-steering antenna array using butler matrix feed network for X-band applications", AEU - International Journal of Electronics and Communications, 2022 — 10 words — 1%
Crossref

15 Han Ren, Peizhao Li, Yixin Gu, Bayaner Arigong. "Phase Shifter-Relaxed and Control-Relaxed Continuous Steering Multiple Beamforming 4 × 4 Butler Matrix Phased Array", IEEE Transactions on Circuits and Systems I: Regular Papers, 2020 — 9 words — 1%
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16 He Zhu, Ting Zhang, Y. Jay Guo. "Wideband Hybrid Couplers With Unequal Power Division/Arbitrary Output Phases and Applications to Miniaturized Nolen Matrices", IEEE Transactions on Microwave Theory and Techniques, 2022 — 9 words — 1%
Crossref

17 Dongwei Wang, Ersin Polat, Henning Tesmer, Holger Maune, Rolf Jakoby. "Switched and Steered Beam End-Fire Antenna Array Fed by Wideband Via-Less Butler Matrix and Tunable Phase Shifters Based on Liquid Crystal Technology", IEEE Transactions on Antennas and Propagation, 2022 — 8 words — 1%
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Crossref

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