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A novel planar four-way power divider with large dividing ratio

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A R T I C L E I N F O

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A B S T R A C T

In this paper, a novel planar four-way power divider with symmetrical simple structure based on microstrip line is presented, and it's design formulas are deduced. It can achieve arbitrary power dividing ratio, ideal matched ports, ideal isolation between four ports, and the largest power dividing ratio can be 33:1 when the port impedance is 50 Ω and the maximum ring-line impedance is 120 Ω. The relative phase difference of four output ports are 0, $\pi/2$, π, $\pi/2$ respectively. The structure has ideal matched ports and isolation between four ports. It is suitable for high-power application. Finally, an experimental prototype with power dividing ratio 5.76:5.76:1:1 is simulated and measured respectively. The measured results validate the proposed method.

1. Introduction

Power dividers are widely used for microwave circuits that construct power splitters, balanced amplifiers, antenna feeding networks, and so on. The Wilkinson *n*-way power dividers [1–5] are the most widely used for power allocation. Its main advantages are electrical symmetry, low insertion loss, high isolation between output ports, and matched conditions at all ports [6,7]. Another traditional power divider is proposed by Gysel [7,8], which is more suitable for high-power applications and easier realized in microstrip or stripline and moderately high *n* than others. However, both of them have nonplanar structure for $n > 2$.

The first planar divider is presented by Galani and Temple [9] and it is a single-stage fork, four- or seven-way hybrid. Explicit formulas are developed by Saleh for the scattering parameters of single- and two-stage fork, n-way hybrids [6]. Then a 12-way planar electrically symmetric two-stage fork hybrid power divider is realized [10]. Yau, Schellenberg and Shih present another planar divider, which utilizing a Dolph-Tchebycheff tapered transmission line [11]. Then a method of least squares is proposed to realize the design goals of the planar multi-section and N-way fork power divider/combiner for an arbitrary power division ratio in [12]. Obviously, they all resemble the type of the Wilkinson power divider, which named the fork hybrid because of their geometry. Besides this kind of planar divider, an odd number *n*-way power divider circuit structure is developed by Chao [13] and composite right/left handed transmission line are used as a technique to design power dividers [14–16], which are more like a rat-race. However, the impedance of microstrip only can achieve 20–120 Ω in engineering practice, so the structure mentioned above cannot suitable for large power dividing ratio.

In addition, a planar microstrip line three-way power divider is presented in [17]. The structure can be regarded as a parallel connection of two branch directional couplers. But it only realize power dividing ratio 1:2:1.

In this paper, a novel eight-port circuit is presented to design the power divider, which splits an input signal into four output signals. The structure provided in this paper has several main advantages as follows and the comparisons with former works are shown in Table 1:

(1) planar symmetrical simple structure;
(2) arbitrary power dividing ratio z^2k^2: z^2: 1: k^2, especially for large power dividing ratio (when the port impedance is 50 Ω and the maximum ring-line impedance is 120 Ω, the largest ratio can be 15 dB), where z and k represent microstrip branch-line impedance Z_3 and Z_6 shown in Fig. 1;
(3) ideal matched ports;
(4) ideal isolation between four outputs;
(5) suitable for high-power applications.

The design formulas are deduced through the analysis of four mode. An experimental prototype with power dividing ratio 5.76:5.76:1:1 is simulated and measured respectively. The consistency between the simulated and measured results validates the proposed design.

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Table 1
Comparisons with former works.

Provide	Planar	Largest power dividing ratio	Structure	Type of transmission line	Way of divider
[1]	No	Not mentioned	Fork	Waveguide	N-way
[7]	No	Not mentioned	Fork	Stripline	N-way
[8]	Yes	Not mentioned	Fork	Microstrip	4/7-way
[11]	Yes	Not mentioned	Rat-race	Microstrip	Odd number N-way
[12]	Yes	3 dB	Rat-race	Microstrip	3-way
This paper	Yes	15 dB	Rat-race	Microstrip	4-way

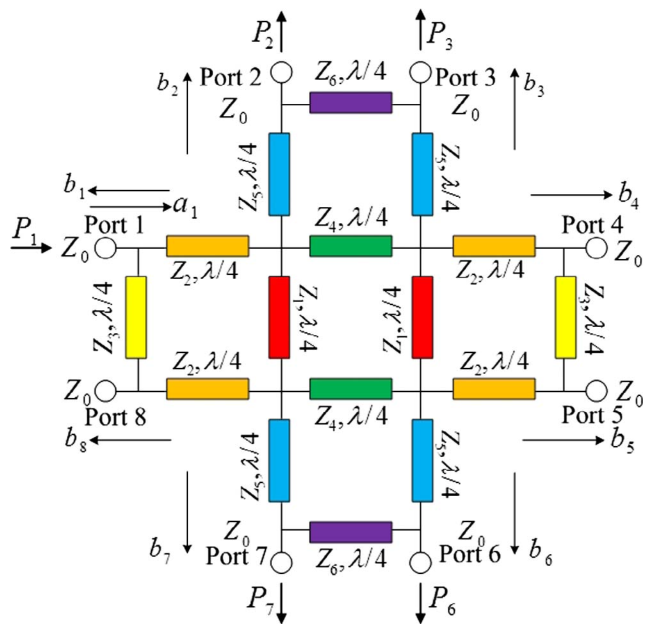

Fig. 1. Planar four-way power divider.

2. Four-way power divider with large dividing ratio

2.1. Theoretical analysis

The structure of the planar four-way power divider is shown in Fig. 1. It is vertically and horizontally symmetrical. Z_1,Z_2,Z_3,Z_4,Z_5, and Z_6 denote the impedance of each section, Z_0 presidents the impedance of ports, $\lambda/4$ indicate the length of each arm.

Considering the symmetric and the reciprocity, the S matrix of the structure can be set as

$$\mathbf{S}=\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} & S_{17} & S_{18}\\ S_{12} & S_{11} & S_{23} & S_{24} & S_{25} & S_{26} & S_{27} & S_{28}\\ S_{13} & S_{23} & S_{11} & S_{34} & S_{35} & S_{36} & S_{37} & S_{38}\\ S_{14} & S_{24} & S_{34} & S_{11} & S_{45} & S_{46} & S_{47} & S_{48}\\ S_{15} & S_{25} & S_{35} & S_{45} & S_{11} & S_{56} & S_{57} & S_{58}\\ S_{16} & S_{26} & S_{36} & S_{46} & S_{56} & S_{11} & S_{67} & S_{68}\\ S_{17} & S_{27} & S_{37} & S_{47} & S_{57} & S_{67} & S_{11} & S_{78}\\ S_{18} & S_{28} & S_{38} & S_{48} & S_{58} & S_{68} & S_{78} & S_{11} \end{bmatrix} \tag{1}$$

There are eight unknown parameters (S_{11},S_{12},S_{13},S_{14},S_{15},S_{16},S_{17},S_{18}). The traditional even-odd mode method will be complex in this case. The elements of **S** are then calculated through double even-odd mode method, which just need analysis four modes that each can equivalent to one simple two-port network (showed in Fig. 2).

2.1.1. Even-even mode

The ABCD matric and the normalized ABCD matric of even-even mode at the center frequency can be calculated by

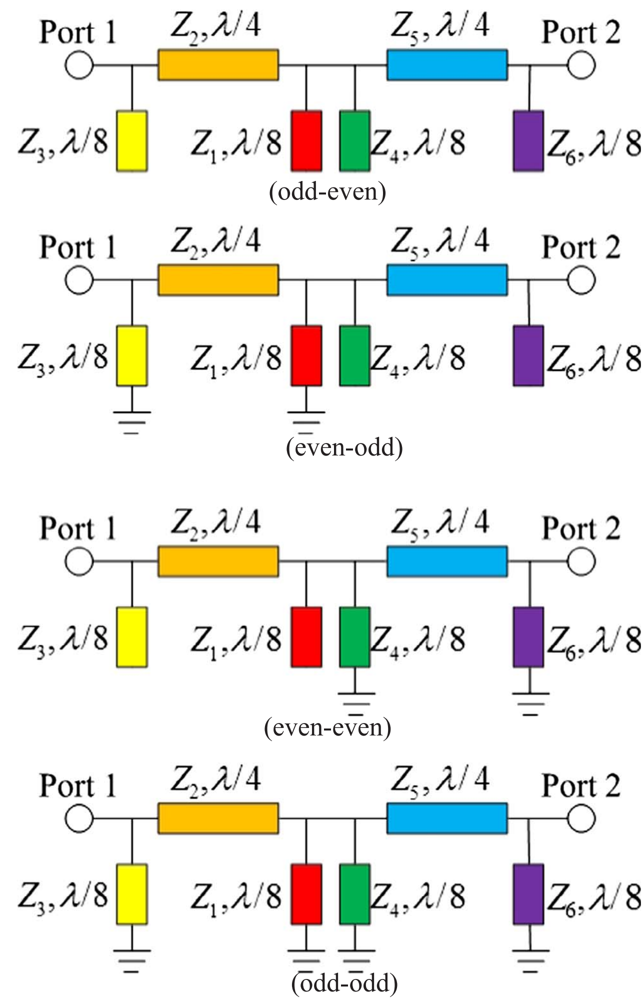

Fig. 2. Equivalent circuit configurations of the proposed structure under the double-even-odd symmetric excitations.

$$\begin{bmatrix} A_{ee} & B_{ee}\\ C_{ee} & D_{ee}\end{bmatrix}=\begin{bmatrix} 1 & 0\\ j\frac{1}{Z_3} & 1\end{bmatrix}\begin{bmatrix} 0 & jZ_2\\ j\frac{1}{Z_2} & 0\end{bmatrix}\begin{bmatrix} 1 & 0\\ j\frac{1}{Z_1} & 1\end{bmatrix}\begin{bmatrix} 1 & 0\\ j\frac{1}{Z_4} & 1\end{bmatrix}\begin{bmatrix} 0 & jZ_5\\ j\frac{1}{Z_5} & 0\end{bmatrix}\begin{bmatrix} 1 & 0\\ j\frac{1}{Z_6} & 1\end{bmatrix} \tag{2}$$

$$\begin{cases}\begin{bmatrix} \widetilde{A}_{ee} & \widetilde{B}_{ee}\\ \widetilde{C}_{ee} & \widetilde{D}_{ee}\end{bmatrix}=\begin{bmatrix} A_{ee} & B_{ee}\\ C_{ee} & D_{ee}\end{bmatrix}\\ A_{ee}=D_{ee}\end{cases} \tag{3}$$

Then the corresponding S_{11ee},S_{12ee},S_{21ee},S_{22ee} are

$$S_{11ee}=S_{22ee}=\frac{\widetilde{B}_{ee}-\widetilde{C}_{ee}}{\widetilde{A}_{ee}+\widetilde{B}_{ee}+\widetilde{C}_{ee}+\widetilde{D}_{ee}} \tag{4}$$

$$S_{12eee}=S_{21ee}=\frac{2}{\widetilde{A}_{ee}+\widetilde{B}_{ee}+\widetilde{C}_{ee}+\widetilde{D}_{ee}} \tag{5}$$

2.1.2. Even-odd mode

The ABCD matric and the normalized ABCD matric of even-odd mode at the center frequency can be calculated by

$$\begin{bmatrix} A_{eo} & B_{eo}\\ C_{eo} & D_{eo}\end{bmatrix}=\begin{bmatrix} 1 & 0\\ j\frac{1}{Z_3} & 1\end{bmatrix}\begin{bmatrix} 0 & jZ_2\\ j\frac{1}{Z_2} & 0\end{bmatrix}\begin{bmatrix} 1 & 0\\ j\frac{1}{Z_1} & 1\end{bmatrix}\begin{bmatrix} 1 & 0\\ -j\frac{1}{Z_4} & 1\end{bmatrix}\begin{bmatrix} 0 & jZ_5\\ j\frac{1}{Z_5} & 0\end{bmatrix}\begin{bmatrix} 1 & 0\\ -j\frac{1}{Z_6} & 1\end{bmatrix} \tag{6}$$