A novel quasi-planar power divider with extra 180° phase difference and full bandwidth

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Abstract: A novel planar E-plane waveguide power divider with extra 180° phase difference and full bandwidth is proposed. It is basically an E-plane waveguide T-junction power divider with its input port rotated around its axis by 90° and arranged symmetrically to form a planar structure. A sample power divider is then designed, fabricated and tested. The test results indicate that, in a relative bandwidth of 40%, the reflection coefficient is lower than -20 dB and the extra phase difference between the two output ports is 180° within an error of $\pm 1.5^\circ$.

Keywords: waveguide, T-HE power divider, extra 180 phase-difference

Classification: Power devices and circuits

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1 Introduction

With the rapid development of microwave systems, waveguide power dividers are very popular due to its low insertion loss and high power capacity. Among them, waveguide T-junction (E-plane [1, 2, 3] or H-plane [4, 5, 6]) power dividers are often used for their simple and compact structures. In practical application, the performance of the power divider, especially the phase difference between the output ports, affects the entire system. The schematic with electric field polarization of a conventional E-plane T-junction is shown in Fig. 1(a), from which it can be seen that the phase difference between the output ports is 180° . But in practice, the E-plane output ports always are bent to the same direction of the input port as shown in Fig. 1(b), and then, the phase difference between output ports will be 0° . This characteristic is useful in practical application and however, in special applications such as planar integration and phased-array antenna [7, 8, 9, 10], an extra phase difference of 180° between the output ports maybe necessary.

Fig. 1. (a) Conventional E-plane T-junction, (b) bent E-plane T-junction, (c) T-HE power divider and (d) bent T-HE power divider's schematic with electric field polarization.

A novel quasi-planar waveguide power divider with E-plane output ports is introduced in this paper. The phase difference between output ports can realize extra 180° phase difference than conventional ones. The operating bandwidth of the divider nearly covers standard waveguide (WR28: $a = 7.112$ mm, $b = 3.556$ mm) working bandwidth. A sample with three ports is then manufactured and tested. The design consideration and the tested results will also be stated in this paper.

2 Design consideration

As shown in Fig. 1(a) and (b), the output ports of the conventional E-plane T-junction are directly arranged at each side of the input port symmetrically. The electric field of the input port is in the same plane as that of the two output ports, and the phase difference of the two output ports will change with their output directions. Bearing this in mind, as shown in Figs. 1(c) and 2(a), if the input port of a E-plane T-junction is further rotated around its axis by 90° and arranged symmetrically, because the operation TE_{10} mode does not change, its field will rotate in the coupling cavity and a novel E-plane power divider with in-phase outputs with respect to it can be achieved. When the output ports are bent to the input port direction, the new structure will realize anti-phase outputs between the output ports. By comparing the electric field polarizations shown in Fig. 1(a) and (c), Fig. 1(b) and (d), it can be clearly seen that the new structure can achieve extra 180 degree phase output whether or not the output ports are bent to the input port direction.

In order for ease of fabrication, the structure has the same top plane and the power divider is quasi-planar and is therefore easy to be integrated with other waveguide components or circuits. We can call the proposed power divider T-HE power divider for short because the top common plane of the power divider is parallel to both the E-field of the output ports and the H-field of the input port.

Fig. 2. (a) Basic structure and (b) 3D view with matching sections of a planar T-HE power divider

The basic structure of the proposed divider is shown in Fig. 2(a). It consists of three parts: a horizontally positioned input port, a coupling cavity and two vertically positioned output ports. In order to achieve equal amplitude division, the entire structure is arranged symmetrically with respect to the E-plane of the input port. Several stepped impedance transformers, as shown in Fig. 2(b), are added between the input port, output ports and coupling cavity respectively for broadband-matching. The front view and top view with most dimensions of the last model is shown in Fig. 3(a), 3(b). Among them, the coupling cavity width is b , length a , height h . The length, width and height of the waveguide segments are a_{lk} , b_{lk} , d_{lk} , respectively, with $l = 1$ and 2 , and $k = 1, 2, 3$, and 4 . $l = 1$ corresponds to the input port and $l = 2$ is the output port, while different k corresponds to different waveguide stepped transformers. All the waveguide sections are transversely centred with their specific ports. In order to further reduce the return loss and increase the working bandwidth to a better extent, a rectangular ridge with

dimensions of length w , height h and width d is inserted to the cavity on the side opposite to the input port, and the first section of the output port is deviated from the rear side of the cavity by s . The top surfaces of all structures are aligned in a common horizontal plane to prompt the manufacture of the power divider and in particular to integrate a power divider network.

Fig. 3. (a) Front view and (b) top view with most configuration parameter definitions

3 Optimization and tested results

To realize the design, we build and simulate an sample power divider using commercial software “CST Microwave Studio”, the central working frequency is set at 33.5 GHz. As shown in Fig. 3, all the ports size are assumed to be the same dimensions as the standard WR28 waveguide. The original length of every step impedance transformer is assumed to be $\lambda/4$, where the parameter λ represents the wavelength corresponding to the central frequency; and the original waveguide width and height are set to be the same as the input and output ports.

Since the designed structure is a simple three ports, non-destructive and mutually beneficial network, the output ports are not matched and the entire structure is symmetrical with the E-plane of the input port, there is no isolation between the output ports [11]. Table I shows the most optimized configuration parameters of sampling T-HE power divider, and Fig. 4 shows the simulated results of S_{11} and S_{21} parameters. The results indicate that the insertion loss is within 3.025 ± 0.02 dB, the return loss is better than 20 dB, and the phase difference between output ports is 0° in bandwidth from 26.4 to 39.8 GHz.

Table I. The most optimized configuration parameters of the sample power divider.

Variables	Value (mm)	Variables	Value (mm)
a	5.73	b_{23}	2.32
a_{11}	6.56	d_{11}	2.19
a_{12}	7.35	d_{12}	2.06
a_{13}	6.87	d_{13}	1.38
b	2.21	d_{21}	2
b_{11}	2.93	d_{22}	2.41
b_{12}	2.67	d_{23}	0.73
b_{13}	1.62	w	4.39
b_{21}	3.33	h	5.37
b_{22}	3.11	off	1.4

Fig. 4. Optimization and Tested Results: (a) Insertion loss (b) Return loss (c) Phase difference of the output ports (d) Machined sample

According to the designed configuration parameters, a T-HE power divider sample is fabricated. All the inner corners of it are bent radius 0.75 mm and the integrated structure or network has a common top surface, making it easy to manufacture the entire structure with conventional computerized milling machines. The size of the last machined sample is $21 \times 24 \times 25$ (mm), which is very compact. Fig. 4 also shows the tested results of the divider, where it can be seen that the output ports insertion loss is within 3.0 ± 0.1 dB, the return loss is better than 20 dB, and the phase difference between output ports is $0 \pm 1.5^\circ$, they can match the simulated results well. The little unbalance in amplitude and phase difference

appearing in the results is mainly caused by assembling and fabrication errors. The connection between the coaxial waveguide adapter flange and the two ports flange may not be completely flat, which is an additional factor in the above test error.

Table II. Recently reported E-plane waveguide power divider

Technology	Phase difference of output ports before being bent	Phase difference of output ports after being bent	Fractional bandwidth	Return loss
Ref. [1]	180°	0°	23%	15 dB
Ref. [2]	180°	0°	32.2%	17 dB
Ref. [3]	180°	0°	12.12%	20 dB
This work	0°	180°	40%	20 dB

Table II shows the comparison of some other recently reported E-plane waveguide power dividers. It can be clearly seen the phase difference between output ports of T-HE power dividers in this work can realize extra 180° phase difference outputs compared with other E-plane power dividers from the table. Furthermore, the fractional bandwidth and insertion loss of the proposed structure are superior to other designs, and it is easier to be assembled and fabricated.

4 Conclusion

In this paper, a novel T-HE waveguide junction which is a planar structure is introduced. The operated bandwidth of the divider nearly covers standard WR28 waveguide working bandwidth. The input port is rotated around its axis by 90° and the phase difference of extra 180° between output ports is realized. The top plane of the entire structure is common so that it can be simply fabricated with CNC milling machine. A model of the T-HE power divider is built and then optimized it by computer. A sample is built and then tested to verify the design, and the tested results show the good performance. We believe the divider can achieve better capability with precision machining and assembling and closer contact between the flange conditions.