Full Waveguide-band E-plane Power Divider with High Output Power Ratio

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Abstract

This paper presents a new *E*-plane power divider with high output power ratio that operates over the full rectangular waveguide band. The proposed divider consists of an *E*-plane junction with rounded corners and a smoothly tapered septum. Output ratios of up to 10 are realized by offsetting the septum while output power ratios greater than 10 are achieved by additionally reducing the broad-wall width in the output waveguides with smaller power. Optimum dimensions of the proposed divider are obtained using a commercial electromagnetic-wave simulation tool. A design is given for a power divider in the WR-10 waveguide that has reflection coefficient of less than –20 dB over 75-110 GHz and output power ratios up to 100 at 75 GHz.

요 약

본 논문은 사각형 도파관 전대역에서 동작하며 큰 출력비를 가지는 전계면 전력분배기를 제안한다. 제안된 분배기는 모서리가 둥글게 처리된 전계면 접합과 부드럽게 테이퍼된 격벽으로 구성된다. 출력비가 10까지의 경우 격벽의 오프셋을 통하여 얻고 10 이상의 출력비는 추가적으로 전력이 더 작은 출력 도파관의 광벽의 폭을 줄임으로써 얻는다. 상용 전자파 시뮬레이션 툴을 사용하여 제안된 분배기의 최적 치수를 얻었다. 75-110 GHz에서 -20 dB 이하의 반사계수를 가지며 75 GHz에서 100까지의 출력비를 가지는 WR-10 도파관의 전력분배기의 설계를 제시하였다.

Keywords
power divider, *E*-plane, rectangular waveguide, full waveguide band, high output power ratio

I. Introduction

The power divider is one of the building blocks of waveguide components such as multiplexers, transmitters and receiver modules and array feed networks. Wideband power dividers with high output power ratio are often required in the feed network of the array of waveguide radiators [1][2]. Full waveguide-band power dividers have been investigated for *H*-plane [3] and *E*-plane [4] geometries. Literature on wideband power dividers with high output ratio is quite limited. Gómez and co-workers presented an *E*-plane gamma-junction power divider with output ratios of up to 10 [5], while Huang and co-workers investigated an *E*-plane *T*-junction

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power divider with output ratios of up to 4 [6].

In this paper, we present a new *E*-plane power divider that provides the output ratio of up to 100. The proposed power divider is structurally simple and can easily be fabricated using split-block technique or metal casting. The design and performance of the proposed power divider are presented below.

II. Power Divider Structure

The *E*-plane junction power divider in a rectangular waveguide shows high reflection since it has large junction discontinuity reactance and no measure for input impedance matching. Fig. 1 shows a waveguide *E*-plane junction divider whose reflection coefficient is shown in Fig. 2 [7].

In Fig. 2, we see that the reflection coefficient of an uncompensated *E*-plane junction in WR-10 waveguide ranges from -8 dB at 75 GHz and -3 dB at 110 GHz. Clearly the *E*-plane junction requires matching structures if it is to be used as a power divider. The E-plane junction can be compensated over narrow or wide frequency bandwidths. In this paper we present an *E*-plane power divider structure that provides reflection of less than -20 dB and high output power ratio over the full bandwidth of the WR-10 waveguide.

Fig. 3 shows the structure of the proposed power divider. The power divider consists of a *T*-junction with rounded corners and a smoothly tapered septum. The output waveguides are denoted by Port 2 and Port 3, whose output power is P_2 and P_3, respectively. Output power ratios P_2/P_3 of up to 10 are achieved by offsetting the septum as shown in Fig 3. The maximum offset is dictated by the smallest possible gap between the septum tip and the rounded corner that can accurately be fabricated.

For power ratios higher than 10, the broad-wall width of the Port 3 waveguide is linearly tapered and directly connected to the output standard waveguide

for as shown in Fig. 4. High output power ratios are in effect achieved by reducing the broad-wall width of the Port 3 waveguide below the cut off value.
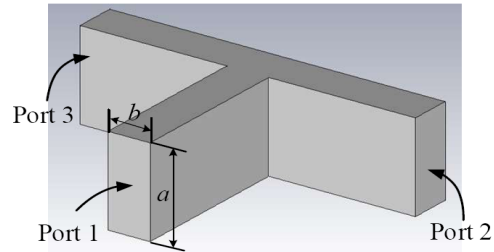

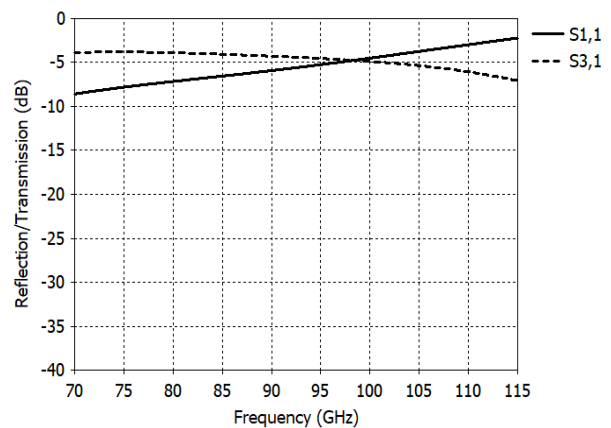Fig. 1. Waveguide *E*-plane junction power divider [7]

Fig. 2. Reflection and transmission (S3,1) coefficients of a waveguide *E*-plane junction divider [7]
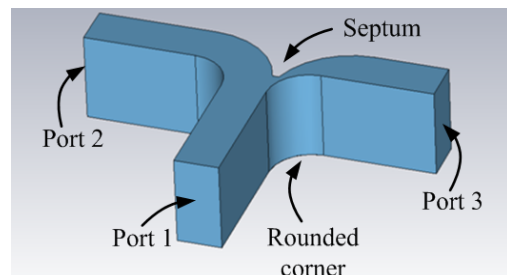

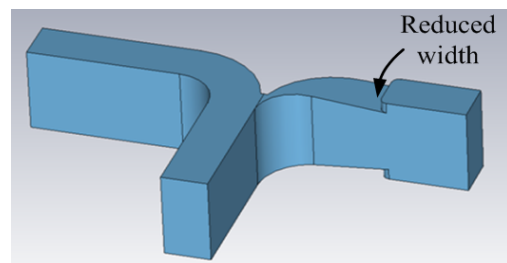Fig. 3. Structure of the proposed power divider

Fig. 4. Power divider with a reduced-width output waveguide for greater output ratios
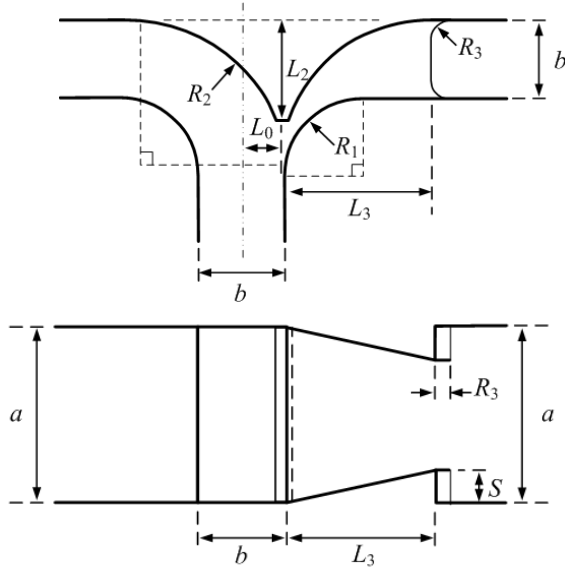
Fig. 5. Dimensional parameters of the proposed divider.
Plan view (top) and side view (bottom)

Fig. 5 shows design parameters of the proposed power divider. Rounded corners of the junction have radius R_1 while the septum has a circular taper of radius R_2. The sharp tip of the septum is removed such that the septum has length L_2. The septum offset L_0 from the center line controls the output power ratio.

For output power ratios of greater than 10, the broad-wall width of the Port 3 waveguide is linearly reduced by $2S$ over a length of L_3. For split-block fabrication using an end mill with a cut along the center line of the broad wall, corners in the step are rounded with radius R_3 (0.25 mm) [8]. Parameters R_1, R_2, and L_2 are kept constant for all values of output power ratios.

III. Power Divider Design

Design of the proposed power divider is carried out using a commercial electromagnetic-wave simulation tool (CST Studio Suite). With R_1 of about $0.7R_2$ and L_0 equal to 0, R_2 and L_2 are adjusted for reflection coefficient of less than -20 dB over the operating frequency range 75-110 GHz of the WR-10 waveguide.
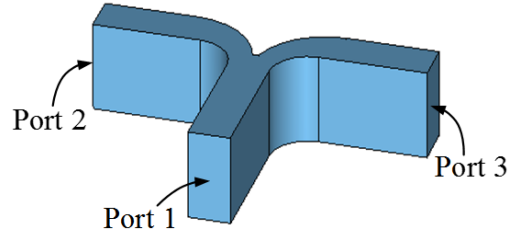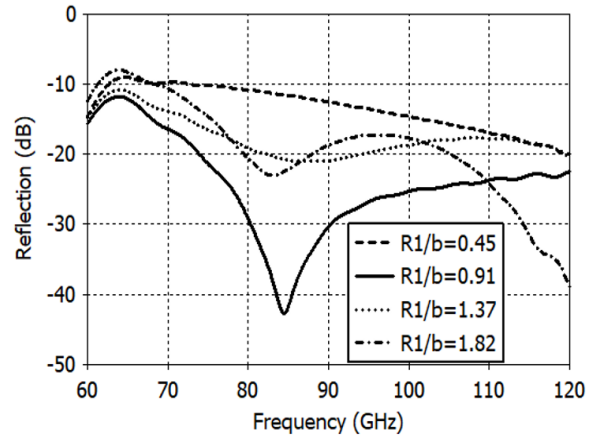

Fig. 6. Divider with no septum offset

Fig. 7. Input reflection versus R_1

Fig. 6 shows the divider with no septum offset for determining the values of R_1, R_2, and L_2. First the effect of R_1 on the input reflection coefficient is investigated with R_2 and L_2 set at their optimum values $1.78b$ and $1.29b$ respectively.

Fig. 7 shows the input reflection coefficient (S_{11}) versus R_1. The optimum value of R_1 is $0.91b$ giving the input reflection coefficient less than -20 dB at 74-120 GHz. Notice that larger values of R_1 does not result in smaller reflection since the optimum value of R_1 is also related the values of R_2 and L_2.

Next the input reflection is calculated for various values of R_2. Fig. 8 shows the result. The optimum value of R_2 is $1.78b$. Larger values of R_2 does not result in smaller reflection since in this case the septum reduces the narrow-wall width of the branching output waveguides. Rather sharp reduction to -42 dB of the reflection at 85 GHz is caused by a mutual resonant cancellation of discontinuity reactances of the divider junction.

Fig. 9 shows the input reflection versus L_2. Smaller values of L_2 make the septum center edge flat and wide while larger values make the septum center edge sharper. The value of L_2 is same as R_2, the septum edge will be sharp as a razor's edge, which is not preferable in manufacturing the power divider. The optimum value of L_2 is $1.29b$

For output power ratios P_2/P_3 of up to 10, only the septum offset L_0 is adjusted. For P_2/P_3 greater than 10, L_0 is set at the value for $P_2/P_3 = 10$ and the taper step S is adjusted with the taper length L_3 fixed at about $1.2a$ (a: the broad-wall width). The input reflection coefficient at Port 1 remains less than -20 dB for all output power ratios.

The proposed concept is applied to the design of a power divider for the WR-10 waveguide operating at 75–110 GHz. Table 1 shows the dimensions of the designed power divider normalized by the narrow wall width b.

Table 1. Dimensions of the proposed divider

L_0/b	R_1/b	L_2/b	R_2/b	R_3/b	L_3/b	S/b
0-0.45	0.91	1.29	1.78	0.158	2.36	0-0.29

Optimum parameters for R_1, R_2, and L_2 have been obtained using the divider with a symmetric septum shown in Fig. 6. The power divider with unequal output power ratios is obtained by offsetting the septum of the structure shown in Fig. 3. The reflection coefficient and the output power ratio are calculated for various values of the septum offset L_0 and plotted in Figs. 10 and 11.

Figs. 10 and 11 show the reflection coefficient and the output power ratio of the structure of Fig. 3 while Figs. 12 and 13 show those of Fig. 4. The input reflection coefficient in all cases is less than -20 dB at 75-110 GHz. The output power ratio is maximum at 75 GHz and gradually decreases as the frequency increases. The maximum output power ratio is about 100 at 75 GHz and 4 at 110 GHz.
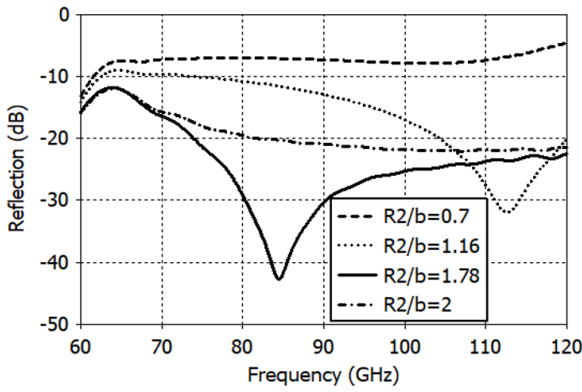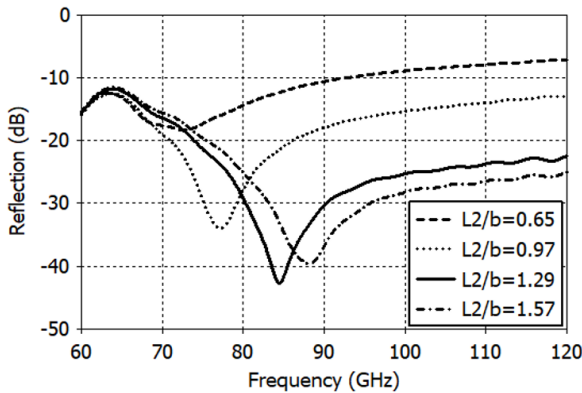

Fig. 8. Input reflection versus $R2$

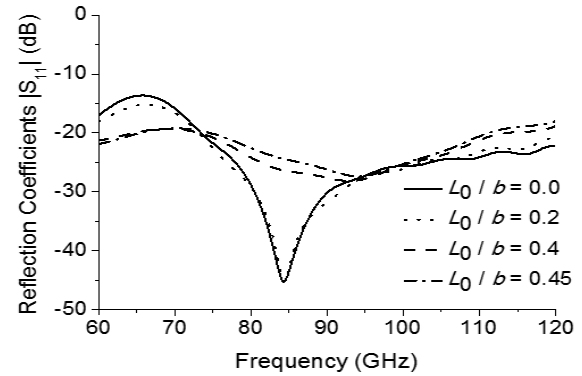Fig. 9. Input reflection versus $L2$

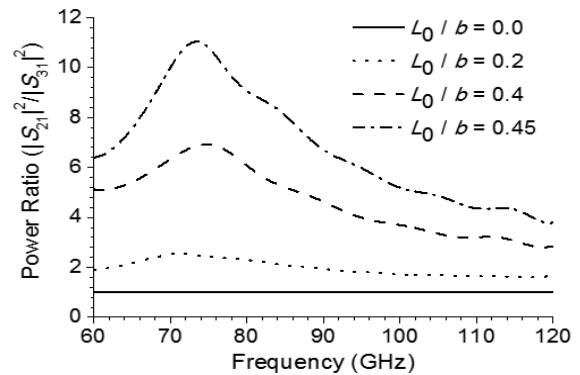Fig. 10. Reflection coefficient of divider shown in Fig. 3

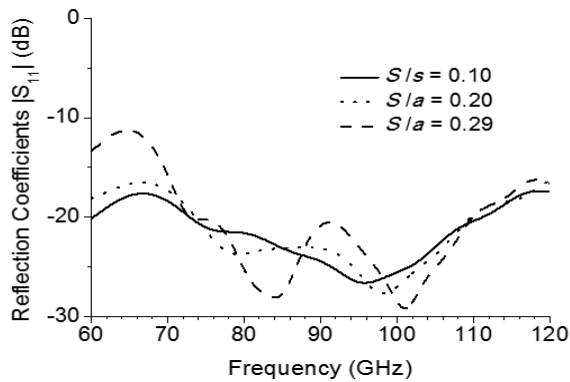Fig. 11. Output power ratio of divider shown in Fig. 3

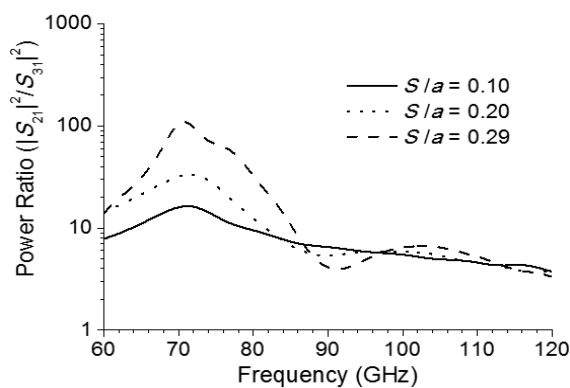Fig. 12. Reflection coefficient of divider shown in Fig. 4

Fig. 13. Output power ratio of divider shown in Fig. 4

The output power ratio can be increased if the input reflection is allowed to increase up to –15 dB. With additional impedance matching structures such as irises, posts and steps in waveguide width and/or height, one can achieve higher output power ratios while keeping the input reflection below –20 dB. With proper impedance matching, power ratios can arbitrarily be increased by increasing the output waveguide taper while keeping reflection coefficient less than a specified value.

IV. Conclusion

In this paper, we presented a new *E*-plane power divider operating over the full rectangular waveguide band with maximum output power ratios of up to 100. Full-band operation is realized with a smooth tapered septum while output power ratio of greater than 10 is obtained by reducing the width of the broad wall in one of the output waveguides. A design

has been presented for the proposed power divider with reflection coefficient of less than -20 dB and power ratio from 4 to 100 over the full waveguide band (75-110 GHz) of WR-10. The proposed power divider offers high output power ratio with simple structure. The proposed power divider concept can be applied to the design of waveguide components where the power needs to be divided over wideband with high ratios.

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