The Substrate Integrated Waveguide T-junction Power Divider with Arbitrary Power Dividing Ratio

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Abstract **─** An X-band H-plane wideband substrate-integrated waveguide (SIW) T-junction power divider with unequal-power-division ratio is presented. Several inductive posts are used to have arbitrary power dividing ratio and also to control the phase difference. The position and diameter of these posts tune the power-split ratio and the phase difference in whole bandwidth. Parametric studies have been done to choose the best positions and diameters to get better results. Two different prototypes have been verified the proposed technique. They are designed and fabricated at a center frequency of 11 GHz. The measured input impedance bandwidths are 54% for Δ_{out} =3 dB and 45% for Δ_{out} =6 dB respectively.

Index Terms **─** Arbitrary power, dividing ratio, power divider, SIW.

I. INTRODUCTION

Rectangular waveguide components are one of the essential parts in microwave and millimeter wave systems. Although metallic rectangular waveguides have been utilized wildly, they are less practical, due to their weight, bulky shape and size and difficult integration with planar circuits. SIW is an alternative technology that overcomes all mentioned problems [1-5]. SIW technology is common because of its easy integration, high quality factor, small dimension, planar structure and easy fabrication. A lot of applications using substrate-integrated-waveguide technology have been reported [1-8], [12].

Power dividers are one of the most fundamental and crucial components of microwave circuits and networks. They are one of the important parts of feeding networks and circuits. Arbitrary power dividing ratio over a wide bandwidth is required for feeding systems which are used in various applications such as phased-array antennas and SIW slot array antennas. In order to reach this goal, some studies have been carried out on investigating of H-Plane T-junction power dividers and lots of articles have been reported [1-7], [9]. In [10], multiple posts are used to demonstrate the flexibility and usefulness of designing SIW power divider. Three inductive posts resulted in a good matching at input port and output ports and also equal power division ratio at two output ports. In [11], unequal power dividing ratio over a broadband is provided by corner structure and three inductive posts. Adjusting the position and diameter of the inductive posts gives an arbitrary power-split ratio. In this article, a novel design of H-plane broadband substrate-integrated waveguide (SIW) T-junction power divider with unequal-power-division is proposed. By using multiple posts technique, the power-split ratio is tuned and the phase difference is controlled in whole bandwidth. The position and diameter of multiple posts adjust the output power-division ratio (Δ_{out}) and phase difference.

II. DESIGN PROCEDURE

A typical structure of T-junction SIW power divider which covers the X-band frequency range (8-12 GHz) is shown in Fig. 1. T-junction SIW power divider consists of three SIW transmission lines and three SIW to microstrip line transitions and an inductive post. In order to have impedance and mode matching transition from SIW to 50 Ω microstrip line is required.

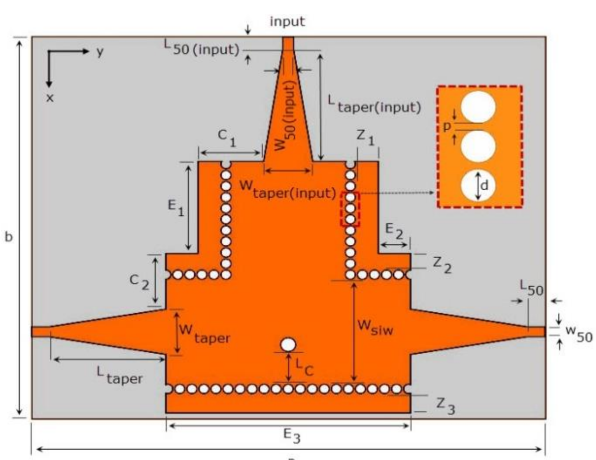

Fig. 1. Geometry of equal output SIW power divider.

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The mode of microstrip line is quasi-TEM and the mode of SIW is TE_{10}, the transition part matches these two different modes. Thus, the transition is an essential part of the project and plays an important role in designing. The design parameters of the equal power divider which are optimized are given in Table 1. The input width of the microstrip line is designed by considering its impedance equal to 50 Ω. The dimension of the SIW parts are calculated based on the equivalent waveguide circuit [3] and the frequency of operation and cut off frequency. Then matching the SIW to microstrip line is defined W_{taper}. All of these parameters have been optimized by HFSS.

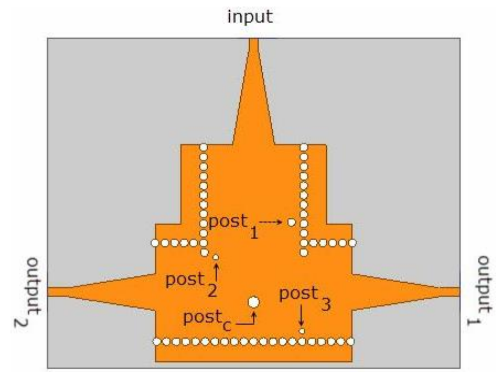
Table 1: The parameters of equal power divider

Parameter	Value	Parameter	Value
W_{50}	1.1 mm	$W_{50(input)}$	1.1 mm
L_{50}	2.61 mm	$L_{50(input)}$	1.38 mm
W_{taper}	4.56 mm	$L_{taper\ (input)}$	12.11 mm
L_{taper}	10.78 mm	$W_{taper\ (input)}$	5.2 mm
W_{SIW}	11.4 mm	L_c	3.75 mm
d	1 mm	P	0.2 mm
C_1	6.4 mm	a	51.2 mm
C_2	6.2 mm	b	41.5 mm
E_1	10 mm	Z_1	2.4 mm
E_2	3.2 mm	Z_2	1.8 mm
E_3	24.4 mm	Z3	2.14 mm

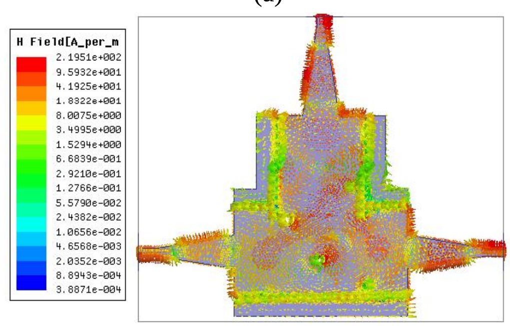
The inductive post reduces reflection in input port and optimizes the S_{11} in a wide frequency band. The important and decisive parameters of this via hole are the diameter and the location. The post is situated at the center of this power divider. The equivalent circuit of inductive post is a parallel susceptance. Altering the diameter and the place of this post resulted in adjusting the reflecting signals, the power division ratio and the phase difference.

The proposed unequal SIW power divider is illustrated in Fig. 2. According to Fig. 2, three inductive posts are used to obtain a different power division ratio at output ports.

As mentioned in [10], placing posts 1 and 2 at the end of input arm in symmetrical way lead to having equal outputs and improving the amount of coupling between the input port and the output ports which reduce S_{11}. So changing the position of one of these posts leads to unequal power-split ratio because in this way most of the power goes to output 1 and the rest goes to the other port. In fact, these posts affect current which has direct relation with H-field, which is shown in Fig. 2 (b). The distance between two posts and the radius of posts are helped to have adjustable power-split ratio. In fact, these posts make a bend which lead the most of power to output 1. In the printed circuit board technology the posts are realized with metallic via. The dimension and location of these two posts, that are located in input arm, specify the various levels of outputs. Post 3, which is situated in output 1, optimize S_{11} and affects the reflection coefficient. In addition, by changing the position of this post, phase difference is tunable.



(a)



(b)

Fig. 2. (a) The SIW power divider with Δ_{out} = 3dB, and (b) the H-field of proposed structure.

As mentioned, the position and diameter of multiple posts adjust the outputs power-division ratio and phase difference. In the following, the effects of changing the position (x, y) and the diameter of posts on return loss have been investigated. As the Fig. 3 shows, 0.5 mm changes in placement of post 1 just affects S_{11} and does not have much effect on Δ_{out}. So x=23.2 mm is chosen in order to have better bandwidth and S11.

Figure 4 depicts that 0.5 mm changes in the y position of post 1 has a great effect on return loss on whole frequency band especially from 8 GHz to 9.5 GHz. Preferred y position is y=30.3 mm, because deeper return loss and wider bandwidth are achieved in this position. Second important parameter to design unequal power divider is the diameter of the inductive posts. Figure 5 demonstrates that the diameter of post 1 change S_{11} and does not affect the outputs.

Based on Fig. 6, the position of inductive post 2 does not have the same result of Δ_{out} in all frequencies. According to Fig. 7, the y position of post 2 play an important role in setting the Δ_{out} and having an arbitrary power division ratio. In addition, it has a great impact on return loss. Choosing the right position is completely crucial. It can be understood from Fig. 8 that, the diameter of post 2, which modify S-parameters, does not have steady effect on whole frequency band. It mostly shows its influence from 8.5 GHz to 9.5 GHz.

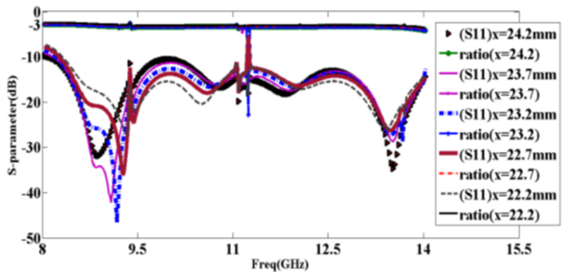


Fig. 3. The effect of changing the x (position) of post 1.

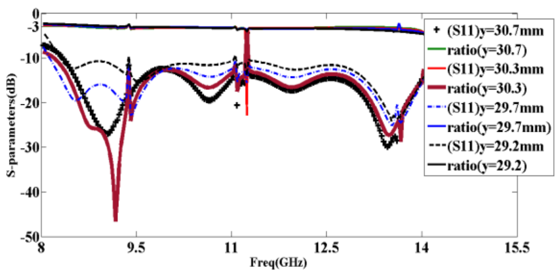


Fig. 4. The effect of changing the y (position) of post 1.

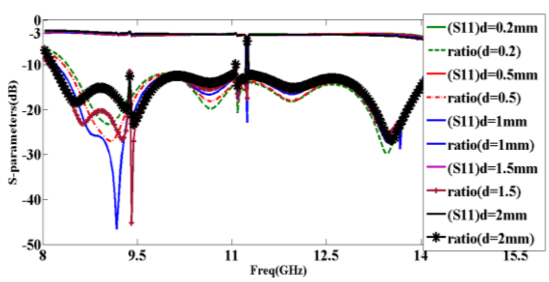


Fig. 5. The effect of changing the d (diameter) of post 1.

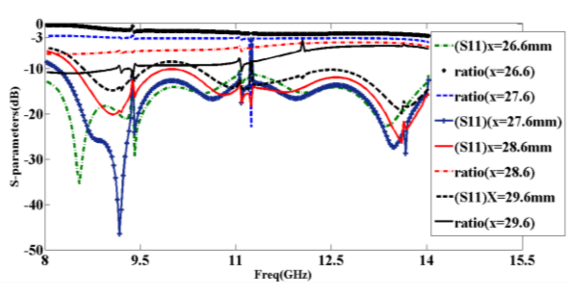


Fig. 6. The effect of changing x (position) of post 2.

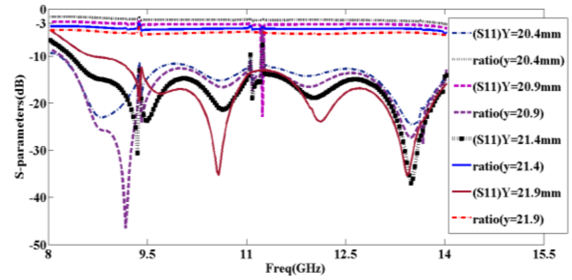


Fig. 7. The effect of changing the y (position) of post 2.

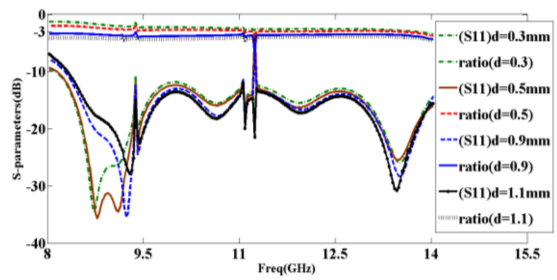


Fig. 8. The effect of changing the d (diameter) of post 2.

Figures 9, 10 and 11 indicate that changing the x position and diameter of post C affect return loss and do not change the power division ratio so much. On the other hand, y position has a challenging effect on Δ_{out}, however the effect is not stable over the whole bandwidth. It has been illustrated in Figs. 12 and 13 that the x position of post 3 is more crucial than the y position and moving the post in the x direction lead to considerable changes in return loss and power division ratio specially from 8 GHz to 10 GHz, which is not steady in whole bandwidth. Little change from 8 GHz to 14 GHz is resulted from altering the y position. The result of modifying the diameter of post 3 is shown in Fig. 14, which indicates that in comparison with the changing the x and y position, it does not affect return loss and Δ_{out} very much.

Post 1 affects the return loss and bandwidth. The best result of the bandwidth depends on choosing the right y position. Although post 1 affects S_{11}, it does not change the Δ_{out}. Any change in the position or the radius of post 2 affects bandwidth, S_{11} and also power-split ratio. The important factor is the y position of this post which leads to steady change of Δ_{out}. The x position of post 3 is really crucial. Altering it results in different S_{11}, bandwidth and unsteady Δ_{out}. Also, by changing the x position of this post the phase difference can be tuned. Post C mostly affects bandwidth and return loss. Choosing the best y position for this post is really important. Finally, it can be seen that post 2 is more effective than post 1 and is the main factor to determine the power division ratio. The most effective parameter is the diameter of post 2 which has a relatively steady change in whole bandwidth. Also, moving post C and post 3 toward y axial lead to significant change. So the position and diameter of these posts are the determinant factors of designing the unequal power dividers.

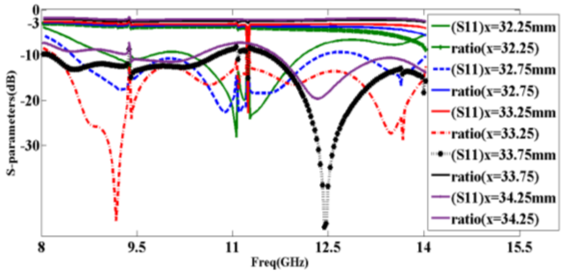


Fig. 9. The effect of changing x (position) of post C.

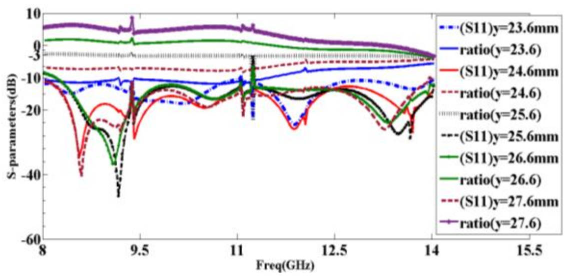


Fig. 10. The effect of changing the y (position) of post C.

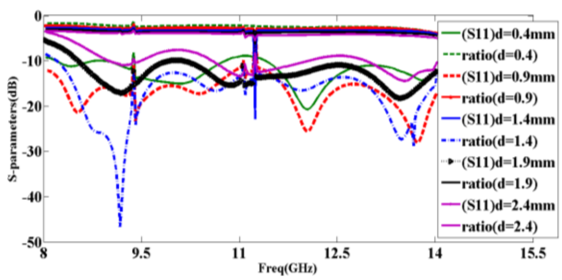


Fig. 11. The effect of changing the d (diameter) of post C.

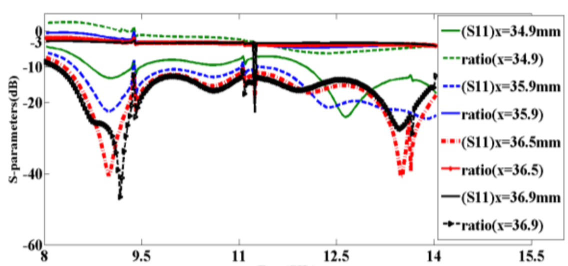


Fig. 12. The effect of changing x (position) of post 3.

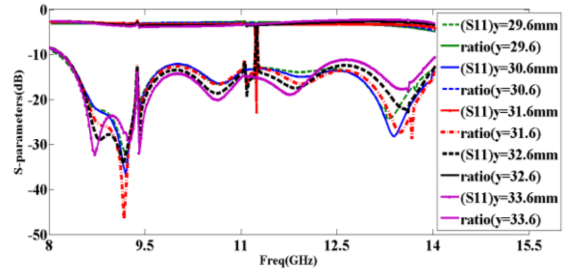


Fig. 13. The effect of changing the y (position) of post 3.

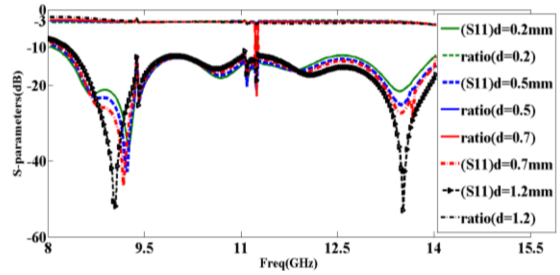


Fig. 14. The effect of changing the d (diameter) of post 3.

The two examples of power dividers with unequal outputs and different power dividing ratio were simulated by Ansoft HFSS. Two prototypes are fabricated on Rog4003 substrate of thickness 0.508 mm and tanδ=0.0027 and dielectric constant is 3.55. Fabricated structures are shown in Fig. 15. The first structure which is designed, has Δ_{out} =3 dB and the Δ_{out} of the second one is 6 dB. The positions of the inductive posts are given in Tables 2 and 3. The simulation results of the presented structures are verified by Network Analyzer and there is a good agreement between simulation results and measured results.

Figures 16 and 17 present the comparison of measured and simulated results. Measured results show that Δ_{out} of the first sample is about 3 dB over the whole bandwidth from 8.2 GHz to 14.3 GHz, that is 54% of the bandwidth. In addition, return loss is better than 13 dB. The phase difference is about 0 degree.

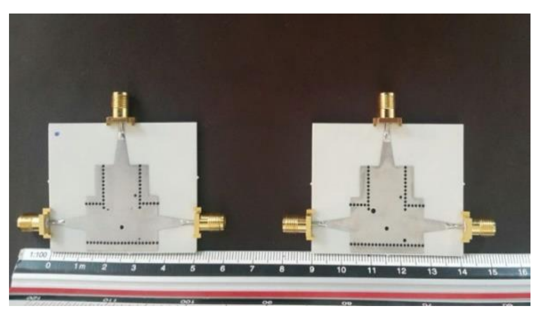


Fig. 15. The proposed power dividers.

Table 2: The position of posts in power divider with Δ_{out} =3 dB

	Position	Diameter
Post 1	(23.2,30.3)	1 mm
Post 2	(27.6,20.9)	0.7 mm
Post 3	(36.9,31.6)	0.7 mm
Post c	(33.25,25.6)	1.4 mm

Table 3: The position of posts in power divider with $\Delta_{ou\ t}$= 6dB

	Position	Diameter
Post 1	(23.2,30.3)	1 mm
Post 2	(27.6,21.1)	1.7 mm
Post 3	(36.7,31.6)	1.2 mm
Post c	(33.1,25.6)	1.4 mm

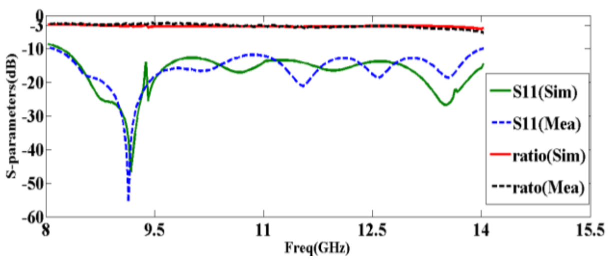


Fig. 16. The S parameters of power divider with Δ_{out} =3 dB.

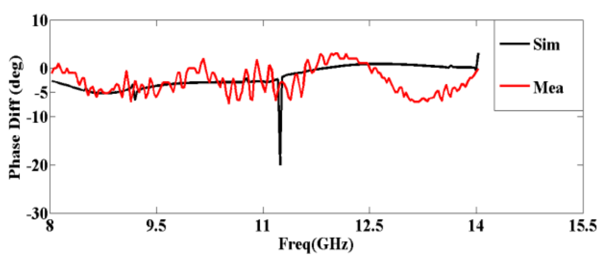


Fig. 17. The phase difference of power divider with Δ_{out} =3 dB ports.

The other power divider with a power division ratio 1:4 has about 45% bandwidth of 8.8 GHz to14.5 GHz (Fig. 18). The S_{11} is about -12 dB over the whole bandwidth. Δ_{phase} is about 180 deg. (shown in Fig. 19). It can be observed that the phase is steady from 8.8 GHz to 14 GHz, which is depicted in Fig. 20. Designing an unequal SIW T-junction with an arbitrary output ratio over a wideband is flexible and effective.

The designs when compared to the previous power dividers with arbitrary power division ratio in Table 4 show significantly better fractional bandwidth and also selectable power-split ratio and phase difference. Phase difference can be near zero or about 180˚.

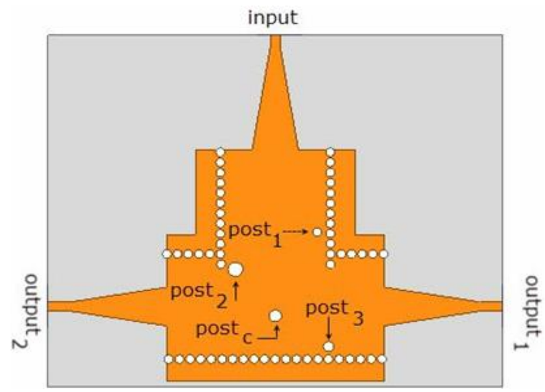


Fig. 18. The SIW power divider with Δ_{out} =6 dB.

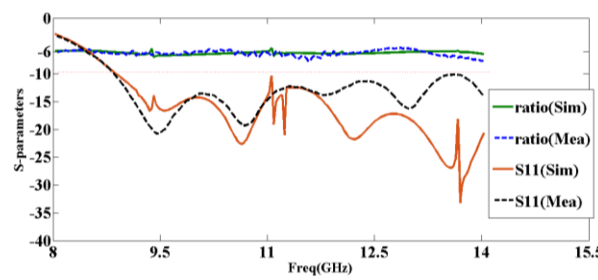


Fig. 19. The S parameters of power divider with Δ_{out} =6 dB.

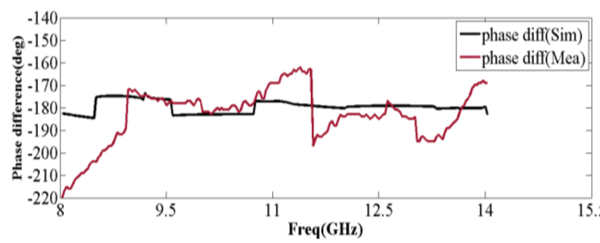


Fig. 20. The phase difference of the power divider with Δ_{out} =6 dB.

Table 4: Comparison between this structure and some reported work

Reference	Δ_{out} (dB)	Center Frequency	Fractional Bandwidth	Adjusted Phase Difference
[10]	3.4	10 GHz	40%	No
[13]	6	23 GHz	12%	No
[14]	6	32.5 GHz	44.06%	No
This work	3	11 GHz	54%	Yes
This work	6	11 GHz	45%	Yes

III. CONCLUSION

In this article, a new design for adjusting the output power level of the SIW T-junction power divider at X-band has been introduced. Using multiple posts in the power divider resulted in flexible and suitable design over a broadband. The position and diameter of post 2, 3 and C are really challenging. In this article the power division ratio is controlled by the diameter and the positions of the posts 1 and 2. In addition, return loss is optimized by using post 3 and post C. The easily modifying of the output level with post's positions and diameters show that this power divider could have an important role in millimeter wave systems.

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