Compact Rectangular Ring Unequal Power Divider

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Abstract — **Three port two-way rectangular ring power divider is described for tight as well as loose power division. These power dividers give more bandwidth than rectangular unequal power dividers. Multiport Network Model (MNM) using de-segmentation method has been developed to analyze this configuration. Parametric study has been done using commercially available software IE3D. Compact rectangular unequal power divider has been achieved by cutting a thin slit on the rectangular patch. Experimental results show good agreement with theoretical results.**

I. INTRODUCTION

Unequal power dividers are extensively used in microwave circuits and systems. Unequal power divider can be realized by using 2-way power divider with unequal characteristic impedances. However, for large power division ratio, the value of one of the impedances becomes too large and hence impractical to fabricate. Also it is very difficult to achieve less than – 10 dB power division using direct coupled couplers [1]. Rectangular unequal power divider is reported for tight as well as loose coupling, but their bandwidth is small [2-3]. In this paper, rectangular ring power divider is discussed, which is compact and gives more bandwidth as compared to rectangular unequal power divider. By cutting a thin slit in the rectangular power divider, the resonance frequency can be reduced. The effects of change in the dimensions of the rectangular slot and the position of the coupled port have been investigated using the Method of Moments (MOM) based commercial IE3D software [4]. Multiport Network Model (MNM) [5-7] for compact rectangular unequal power divider has also been developed using Green's function of rectangular patch and de-segmentation method [5]. Experimental results are in good agreement with theoretical results.

II. RECTANGULAR RING UNEQUAL POWER DIVIDER

A rectangular ring two-way unequal power divider is shown in Fig. 1. It consists of a rectangular patch of length L and width W with a slot of length l and width w at the center of the rectangular patch. Two ports P_1 and P_2 are connected at the middle of the two opposite sides and the third port P_3 is connected along the upper edge. The port width corresponds to the 50 Ω transmission line and its value is calculated using available formulae [8]. When P_3 is moved along the periphery or the slot dimensions are changed, the coupled power at P_3 also varies. For TM_{10} mode, most of the power fed at P_1 appears at P_2 when P_3 is placed at the middle i.e. at $x = 0$, because the voltage null occurs at the middle along the length of the patch. However, due to the finite width of the port, very small power appears at P_3.

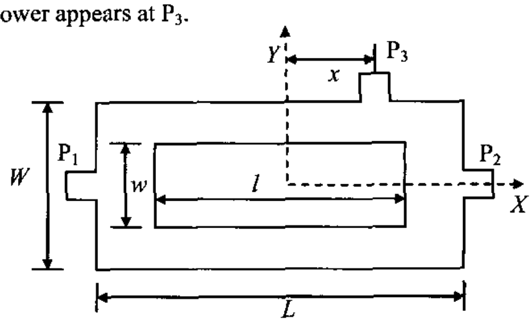

Fig. 1 Rectangular ring 2-way unequal power divider

Depending upon the slot dimensions, the effective electrical length of the patch varies, and by optimizing it, a compact design can be obtained.

MNM has been developed for rectangular ring unequal power divider. Green's function of a rectangular ring is not available and thus the Z- parameters of the rectangular ring unequal power divider cannot be obtained directly. De-segmentation method is used to obtain the Z-matrix of the rectangular ring. According to this method, the rectangular ring can be obtained if a rectangular patch is de-segmented from another rectangular patch of the larger size as shown in Fig. 2.

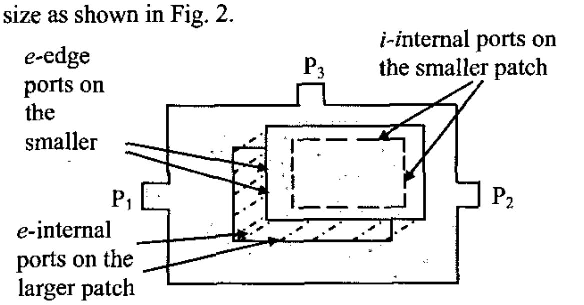

Fig. 2 De-segmentation of two rectangular patches to form a rectangular ring unequal power divider

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III. PARAMETRIC STUDY

Parametric study has been carried out to see the effect of slot dimensions of a rectangular ring unequal power divider with L = 50 mm, W = 10 mm, x = 0, dielectric constant ε_r = 9.8, substrate height h = 0.635 mm and loss tangent tanδ = 0.001. Variations of center frequency f_c, magnitude of S-parameters, bandwidth BW, and % BW with different slot dimensions ($l \times w$) are shown in TABLE I. The ratio of l and w is kept constant for all the cases to maintain ring symmetry. From TABLE I, it can be observed that:

1. Center frequency decreases with the increase in slot dimensions, which is because of the increase in the effective surface current path length.
2. When slot dimensions increase from 5 mm × 1 mm to 45 mm × 9 mm, coupling S_{31} increases from – 17.8 dB to – 7.95 dB and accordingly S_{21} decreases from – 0.36 dB to – 1.02 dB.
3. The BW for $S_{11} \leq -10$ dB increases with the increase in the slot dimension, because of smaller discontinuity and smaller patch capacitance, which ensures smaller Q-factor.

The variation of x also gives a variable power at P_3. When x = 0, i.e. P_3 is located at the voltage null position, then the loading effect due to this port will be very small and most of the input power applied at P_1 will appear at P_2. When slot dimensions are very small with compared to the rectangular patch, the magnitude of voltage at P_1 and P_2 will be almost same with 180° phase difference. Study has been done on a power divider with L = 50 mm, W = 10 mm, l = 30 mm, w = 6 mm, ε_r = 9.8, h = 0.635 mm and tanδ = 0.001 to see the effect of variation of x keeping other parameters of the patch fixed. The effects are shown in TABLE II, which are summarized below.

1. Since the patch, slot and substrate parameters for all the cases remain the same, f_c remains almost constant.
2. Coupled power at P_3 increases with increase in x, because P_3 moves from voltage null position towards maximum voltage. When x increases from 0 to 20 mm, S_{31} increases from – 14.52 dB to – 3.84 dB.
3. When x is 0, loading effect due to P_3 will be negligible and most of the power arrives at P_2. With increase in x from 0 to 20 mm, loading effect due to P_3 increases and return loss increases from – 38.6 dB to –10.0 dB.
4. Changes in S_{21} depend upon the variation in both S_{11} and S_{31}. In this case S_{21} decreased from – 0.46 dB to – 3.47 dB as x increases from 0 to 20 mm.

Experiment has been carried out on a rectangular ring unequal power divider fabricated on low cost glass epoxy substrate. The various parameters are L = 50 mm, W = 20 mm, l = 25 mm, w = 5 mm, x = 0, ε_r = 4.3, h = 1.59 mm and tanδ = 0.02. The experimental and theoretical magnitudes of S-parameters vs. frequency plots are shown in Fig. 3. The experimental results are in agreement with the IE3D results.

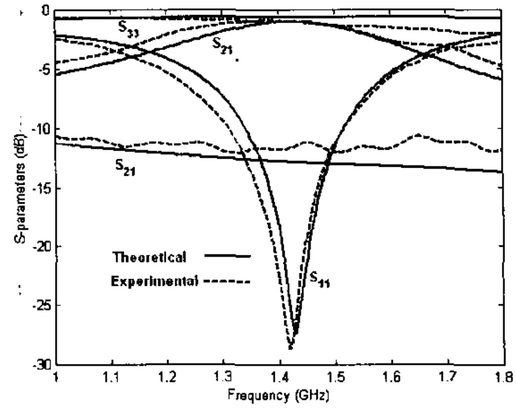


Fig. 3 Experimental and theoretical S-parameter vs. frequency curves for 2-way rectangular ring unequal power divider

IV. COMPACT RECTANGULAR UNEQUAL POWER DIVIDER

From TABLE I, it can be seen that when both l and w increase, then f_c decreases but S_{21} and S_{31} also change. If a thin slit is cut orthogonal to the direction of the surface current as shown in Fig. 4, the effective path length from P_1 to P_2 will be increased but effective dielectric constant of the patch will remain almost the same as that of a rectangular patch without slit. Thus decrease in f_c can be achieved with S_{21} and S_{31} almost unchanged. This configuration behaves like a compact rectangular unequal power divider.

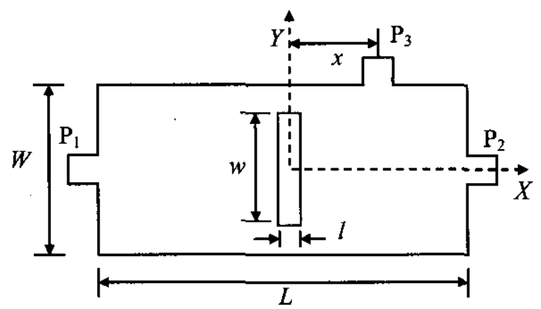
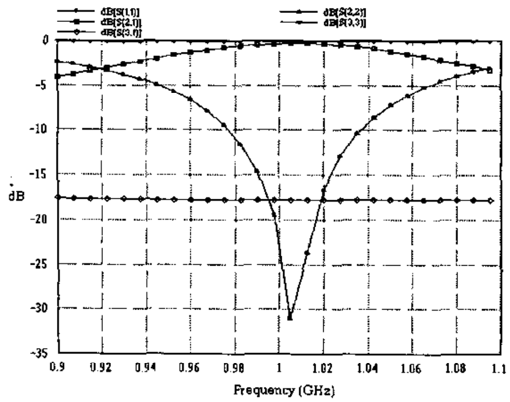


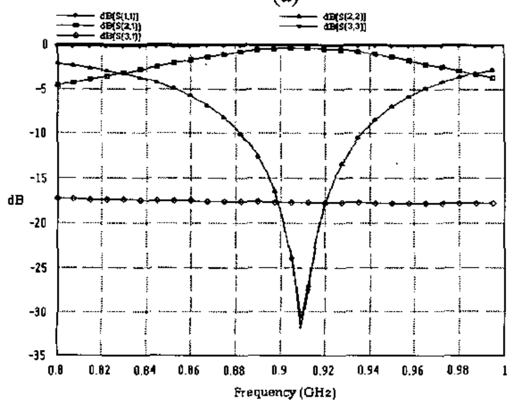
Fig. 4 Rectangular unequal power divider with a slit

The theoretical S-parameters vs. frequency plots for rectangular unequal power divider without and with slit are shown in the Fig. 5 (a) and (b), respectively. The parameters for the rectangular patch are L = 50 mm W =

10 mm, x = 0, ε_r = 9.8, h = 0.635 mm and tanδ = 0.001 and the slit parameters are l = 1 mm and w = 8 mm.



(a)



(b)

Fig. 5 Magnitude of S-parameters vs. frequency curves for rectangular 2-way unequal power divider (a) without slit and (b) with slit

From Fig. 5 (a), it can be seen that coupling at P_3 is – 17.7 dB with a BW of 61 MHz (5.6 %) at f_c = 1.004 GHz. When a slit is cut with l = 1 mm and w = 8 mm from the above rectangular power divider, it gives a compact response as shown in Fig. 5 (b). This configuration gives – 17.5 dB coupling with 57 MHz (6.3%) BW at f_c = 0.908 GHz. Thus, a compact design of 2-way rectangular unequal power divider has been obtained.

Parametric Study has been done to observe the effects of varying the slot dimensions of the compact rectangular power divider on its performance. Variation of f_c, S-parameters, BW and % BW with slot dimensions for a compact rectangular ring power divider (L = 50 mm, W = 10 mm, l = 30 mm, w = 6 mm, ε_r = 9.8, h = 0.635 mm and tanδ = 0.001) are given in TABLE III. From TABLE III, it can be seen that:

1. Center frequency decreases with the increase in the width of the slot which is due to the increase in the effective resonance length, whereas the effective dielectric constant remains almost same.
2. S_{11} is better than 30 dB for all the cases but increases slightly with the increase in the slot width. With the increase of slot width from 0 to 8 mm, S_{21} decreases from – 0.36 dB to – 0.48 dB and S_{31} increases from – 17.8 dB to – 17.4 dB. This slight change is due to the increase in coupled power at P_3. For various applications, these small changes can be ignored.
3. The BW remains almost same for all the cases but due to the decrease in the center frequency, % BW increases slightly.

Experiment has been carried out on a compact rectangular unequal power divider with L = 50 mm, W = 20 mm, l = 2 mm, w = 15 mm, x = 0, ε_r = 4.3, h = 1.59 mm and tanδ = 0.02. The magnitude of S-parameter vs. frequency plots obtained with experiment, IE3D and MNM are shown in Fig. 6. It can be seen that the experimental results show very good agreement with the IE3D and MNM results.

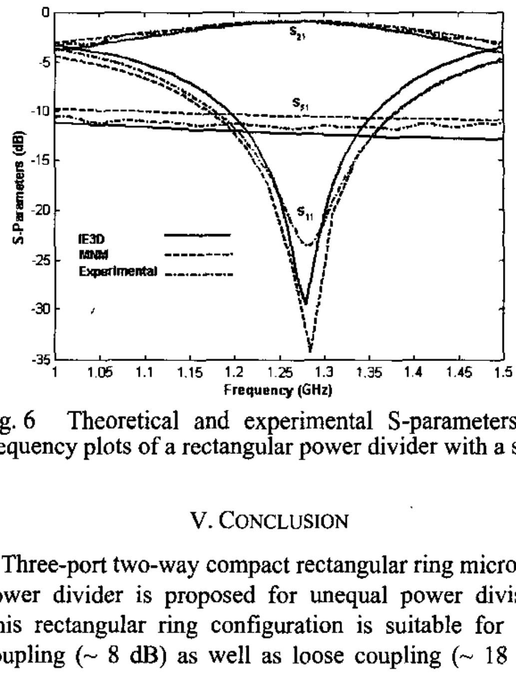


Fig. 6 Theoretical and experimental S-parameters vs. frequency plots of a rectangular power divider with a slit

V. Conclusion

Three-port two-way compact rectangular ring microstrip power divider is proposed for unequal power division. This rectangular ring configuration is suitable for tight coupling (~ 8 dB) as well as loose coupling (~ 18 dB). BW of 10 % and 28 % has been achieved for – 13 dB and – 8 dB power division respectively. Compact rectangular power divider has also been achieved by cutting a thin slot at the center of the rectangular unequal power divider. Experimental results are in close agreement with theoretical results.

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TABLE I

Variation of f_c, S-parameters, BW and % BW with slot dimensions $l \times w$ for a rectangular ring power divider

$l \times w$ (mm × mm)	f_c (GHz)	$\|S_{11}\|$ (dB)	$\|S_{21}\|$ (dB)	$\|S_{31}\|$ (dB)	BW (MHz)	BW (%)
0 × 0	1.007	34.8	0.36	17.8	56	5.6
5 × 1	1.001	34.0	0.37	17.8	57	5.7
10 × 2	0.983	33.3	0.39	17.8	56	5.7
15 × 3	0.952	32.2	0.40	17.5	57	6.0
20 × 4	0.910	33.6	0.42	16.8	56	6.2
25 × 5	0.867	34.5	0.44	15.8	61	7.0
30 × 6	0.826	38.6	0.46	14.5	66	8.0
35 × 7	0.796	42.7	0.51	12.9	81	10.2
40 × 8	0.773	32.2	0.64	10.7	115	14.9
45 × 9	0.758	22.7	1.02	7.95	219	28.9

TABLE II

Variation of f_c, S-parameters, BW and % BW with x for a rectangular ring power divider

x (mm)	f_c (GHz)	$\|S_{11}\|$ (dB)	$\|S_{21}\|$ (dB)	$\|S_{31}\|$ (dB)	BW (MHz)	BW (%)
0	0.826	38.6	0.46	14.5	66	8.0
5	0.824	24.3	0.81	9.8	68	8.3
10	0.819	16.2	1.72	6.0	69	8.4
15	0.814	11.8	2.80	4.4	51	6.3
20	0.813	10.0	3.47	3.8	5	0.6

TABLE III

Variation of f_c, S-parameters, BW and % BW with $l \times w$ for a rectangular power divider with a slit

$l \times w$ (mm×mm)	f_c (GHz)	$\|S_{11}\|$ (dB)	$\|S_{21}\|$ (dB)	$\|S_{31}\|$ (dB)	BW (MHz)	BW (%)
0x0	1.007	34.8	0.36	17.8	56	5.6
1×1	1.000	34.5	0.37	17.6	56	5.6
1×2	0.999	35.7	0.37	17.6	57	5.7
1×3	0.996	33.5	0.38	17.6	56	5.6
1×4	0.985	33.2	0.39	17.6	57	5.8
1×6	0.960	33.8	0.42	17.5	56	5.8
1×8	0.908	31.6	0.48	17.4	57	6.3