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COMPACT WIDEBAND GYSEL POWER DIVIDER WITH ARBITRARY POWER DIVISION BASED ON PATCH TYPE STRUCTURE

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Abstract—A novel Gysel power divider based on patch type structure is presented in this paper. The proposed power divider possesses broad bandwidth, small physical occupation and arbitrary power division. More than 30% bandwidth enhancement is achieved based on the −15 dB input return loss criteria, while 55% size reduction is realized compared with conventional Gysel power divider. What's more, flat dividing is obtained in the design without using additional transmission line sections. Based on the novel structure, a design procedure of power dividers with unequal power division ratios is provided without using narrow microstrip line. To verify the design approach, the proposed power dividers with equal and unequal (2:1 and 4:1) power divisions at the centre frequency 1.5 GHz are fabricated and measured. The results demonstrate that the design can fulfil our goals.

1. INTRODUCTION

Power dividers play an important role in the design of microwave circuits. The Wilkinson power divider has been widely used, and numerous achievements have been published in order to minimize its size [1–3] or to achieve unequal power division [4–6]. Dual-band or wideband power dividers with unequal power division have received growing attention in power divider design [7–16]. However, the Wilkinson power divider has the shortcoming in high power application, since there is no way in it to transfer the generated heat to the surrounding media [17].

The Gysel power divider is devised with several advantages such as high power-handling capability and monitoring capability for

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imbalance at the output ports [18], in which aspects it outperforms the Wilkinson power divider. However, the conventional Gysel power divider has two disadvantages that limit its application. Firstly, the conventional Gysel power divider has a narrow bandwidth for about 30%, which is narrower than that of the Wilkinson power divider. In order to overcome the bandwidth limitation, several methods have been published in the past few years. Through a sequential matching technique, 15% bandwidth improvement has been obtained in [19]. In [20], a modified Gysel power divider has added 32% bandwidth increase based on the multistage technology. Secondly, the conventional Gysel power divider has a large size. So far, the only way to solve this problem is using bent microstrip lines to reduce the dimension [20].

In this paper, a novel Gysel power divider with broad bandwidth based on patch type structure for high power application is proposed. Size reduction is achieved by etching shapes into the rectangular patch. Based on the novel patch type structure, a design procedure with unequal power dividing ratios is provided without using narrow microstrip line. The proposed power divider is much useful in high power application in the concerns that the electrical and physical characteristics of the microstrip remain unchanged, while the heat flow caused by conductor and dielectric losses can be easily handled. Moreover, it is very easier to design and fabricate extremely unequal power divider based on the patch type structure as it avoids using very narrow microstrip lines.

2. DIVIDER WITH WIDE BANDWIDTH

The layout of the proposed novel Gysel power divider is shown in Figure 1. This power divider employs a rectangular patch structure

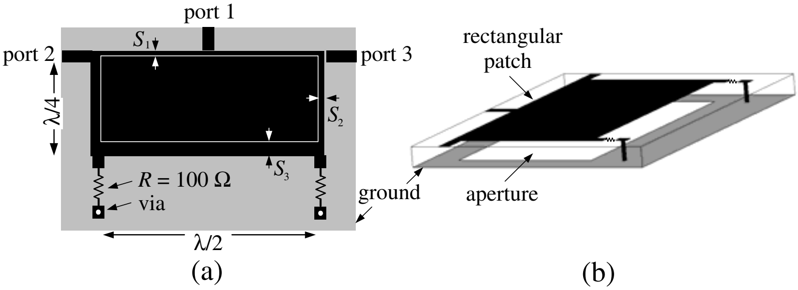


Figure 1. Schematic diagram of proposed patch type divider. (a) Top view. (b) 3-D view.

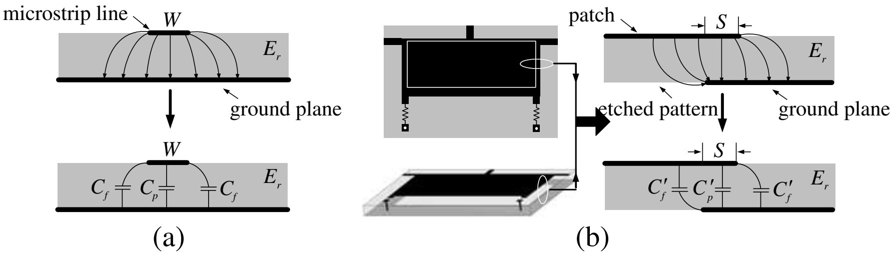


Figure 2. Electric field lines and equivalent capacitances distribution. (a) Conventional microstrip line. (b) Patch type structure with etched pattern in the ground plane.

with etched rectangular pattern in the ground plane to disturb the current distribution and change the patch's characteristics. Two external resistors ($R = 100\,\Omega$) are connected to ground through via holes, which provides a direct path for heat sinking. Cooling systems provided, the capability of handling continuous wave input power would be up to several kilowatts [20], while the physical characteristics and the performance of the patch type structure remain unchanged.

Figure 2 shows the electric field lines and the equivalent capacitance distribution of the conventional microstrip line and the proposed patch structure. The equivalent capacitance of the patch type structure is determined by the parallel-plate region, which is different from microstrip line as can be seen in Figure 2.

The total capacitance of the conventional microstrip line and the patch structure line are defined as C_{total} and C'_{total}:

$$C_{\text{total}} = C_p + 2C_f \tag{1}$$

$$C'_{\text{total}} = C'_p + 2C'_f \tag{2}$$

C_p and C'_p can be calculated from the well-known formula for parallel-plate capacitance:

$$C = \frac{\varepsilon_0 \varepsilon_r S}{d} \tag{3}$$

It can be seen from Figure 2 that the electric field lines and the equivalent capacitance distribution of microstrip line and patch type structure are just in different symmetrical forms: one is axial symmetry while the other is central symmetry. For approximate purpose, we assume that $C'_f = C_f$.

The patch type structure supports quasi transverse electromagnetic waves (quasi TEM), which complicates the analysis of its character. However, using the characteristic impedance for the quasi-TEM approximation:

$$Z_0 = \sqrt{\frac{L}{C}} \tag{4}$$

where

$$L = \frac{1}{v_\varphi^2 C} \tag{5}$$

and

$$v_\varphi = \frac{c}{\sqrt{\varepsilon_r}} \tag{6}$$

The characteristic impedance of the patch type transmission line in Figure 2 can be written as:

$$Z_0 = \frac{1}{v_\varphi C} \tag{7}$$

Based on Equation (7), by tuning the width S, the characteristic impedance of the patch type transmission line can be changed conveniently and the characteristic impedance of the patch type transmission line is about equal to the microstrip line when their width are the same. Without using very narrow microstrip line, high impedance will be achieved by reducing the paralleled region, which can be easily obtained in a conventional PCB process. Moreover, due to the different distribution of electric field, the bandwidth of the proposed Gysel power divider can be enhanced compared with conventional Gysel power divider.

Although the patch type power divider is an alternative to the conventional Gysel power divider as it avoids using narrow lines and provides a broad bandwidth, it also suffers from a larger physical size. In order to reduce the physical dimension of the proposed divider,

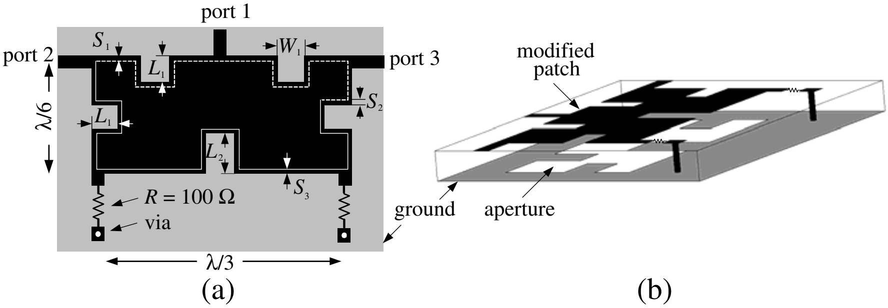
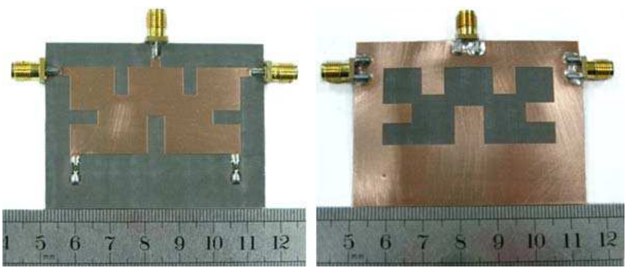


Figure 3. Schematic diagram of modified patch type divider. (a) Top view. (b) 3-D view.

rectangular pattern is etched on the edge of the patch structure in order to form a longer electrical path. Figure 3 shows the layout of modified patch type power divider. The main contribution of size reduction is made by L_1 and L_2, the longer L_1 and L_2 are, the smaller the whole structure will be. However, the value of L_1 and L_2 should be limited so as to avoid overlap and coupling between different rectangular patterns.

Based on the above elaboration, a patch type Gysel power divider is optimally designed at the centre frequency of 1.5 GHz and is fabricated on a substrate with relative dielectric permittivity of 2.65 and thickness of 1 mm. Based on reference [19], the impedances for the coupled parts can be described as: $Z_{S1} = \sqrt{(2)} * Z_0$, $Z_{S2} = Z_0$, $Z_{S3} = Z_0/\sqrt{(2)}$. The input and output ports impedances are fixed to $Z_0 = 50\,\Omega$. The physical dimensions of the divider after optimization are as follows: $L_1 = 8\,\text{mm}$, $L_2 = 11.5\,\text{mm}$, $S_1 = 1.1\,\text{mm}$, $S_2 = 0.8\,\text{mm}$, $S_3 = 1.4\,\text{mm}$. The total occupation of the modified divider is $\lambda/3 \times \lambda/6$. More than 55% size reduction is realized compared with conventional Gysel power divider.

Figure 4 shows a photograph of the proposed divider. The overall size of the divider is 4.5 mm × 6.5 mm. The simulated S-parameters are obtained using Ansoft's High Frequency Structure Simulator (HFSS) and measurement has been carried out using Agilent network analyzer N5230A. The simulated and measured results of the power divider are shown in Figure 6. It can be observed that the operation bandwidth of the proposed patch type power divider is about 60% with the return losses of input and output ports lower than −15 dB. More than 30% bandwidth enhancement is realized compared with conventional Gysel power divider. In addition, the output magnitude imbalance within the 60% bandwidth is less than 1.1 dB, which means the proposed power divider owns the character of flat power dividing. Dues to the



(a) (b)

Figure 4. Photograph of fabricated patch type power divider. (a) Top view. (b) Bottom view.

radiation effect of the patch, the proposed power divider has a slightly higher insertion loss for about 0.4 dB as can be seen from Figure 5. Another 0.2 dB insertion loss is added by the SMA connector when the fabricated divider is under measurement.

The comparisons of the proposed divider with other published Gysel power dividers are summarized in Table 1. The size consideration ($\lambda/6 \times \lambda/3$) in this work and the size comparison with references [18–20] summarized in Table 1 are measured by the electrical length of the power divider instead of the whole substrate area. It can be seen that based on the patch type structure, both bandwidth enhancement and size reduction are obtained without complex design and optimization procedures.

3. DESIGN PROCEDURE OF UNEQUAL POWER DIVISION

Power dividers with unequal power division require very narrow microstrip lines. For example, a 6:1 Wilkinson power divider requires

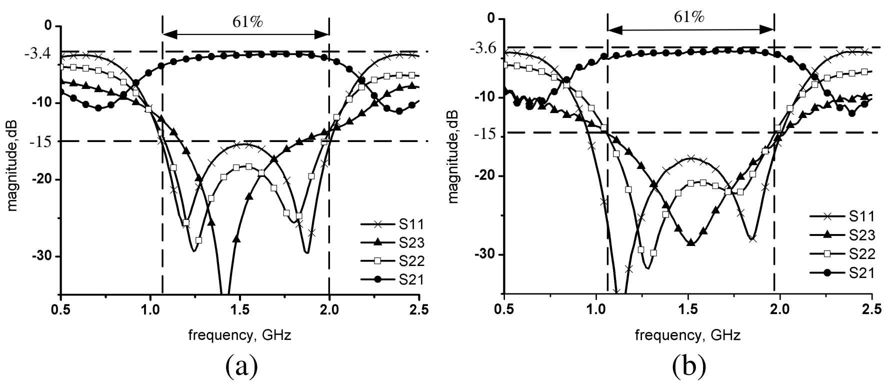


Figure 5. Simulated and measured results of proposed power divider. (a) Simulated results. (b) Measured results.

Table 1. Comparison of the Gysel power dividers.

Type	Bandwidth enhanced technology	Bandwidth	Whole size	Ref.
Microstrip	—	30%	$\lambda/2 \times \lambda/4$	[18]
Microstrip	Sequential matching	45%	$\lambda/2 \times \lambda/4$	[19]
Microstrip	Multistage technology	62%	$\lambda/2 \times 3\lambda/4$	[20]
Patch type	Patch type structure	60%	$\lambda/3 \times \lambda/6$	This work

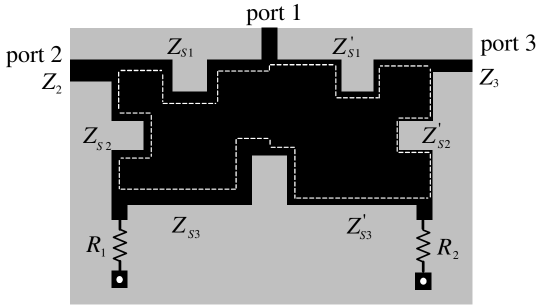


Figure 6. Schematic diagram of patch type divider with unequal power division.

a 207 Ω microstrip line [21], and the realization of a 2:1 power division ratio for the conventional Gysel power divider needs a 0.11 mm microstrip line [22], which are difficult to be physically realized, and a small fabrication error will result in a large degradation in performance. In this section, the realization of unequal power division (2:1 and 4:1) is achieved using patch type structure. High characteristic impedance is realized by decreasing the paralleled region.

Figure 6 shows the layout of the proposed power divider with unequal power division based on the patch type structure. Assuming that the power dividing ratio is K^2 $(P_2/P_3 = K^2)$, the impedances in the right section should be equal to K^2 times as those in the corresponding parts of the left section [22]:

$$Z_2 = Z_0/K, \quad Z_3 = KZ_0 \tag{8}$$

$$Z_{S1} = \sqrt{2}Z_0/K, \quad Z'_{S1} = \sqrt{2}KZ_0 \tag{9}$$

$$Z_{S2} = Z_0/K, \quad Z'_{S2} = KZ_0 \tag{10}$$

$$R_1 = R_0/K, \quad R_2 = KR_0 \tag{11}$$

The selection of impedance values for Z_0 and R_0 is arbitrary. For convenience, Z_0 and R_0 are chosen $Z_0 = 50\,\Omega$ and $R_0 = 100\,\Omega$ at the beginning. The quarter wave line sections Z_{S3} and Z'_{S3} do not affect the impedance matching [17], for a initial choice they are chosen $Z_{S3} = Z_0/\sqrt{2}K$, $Z'_{S3} = KZ_0/\sqrt{2}$. If a power dividing ratio $K^2 = 2\,(P_2 = 2P_3)$ is required, then the characteristic impedances of the patch type divider can be calculated using Equations (8)–(11):

$$Z_2 = Z_{S2} = 35.4\,\Omega, \quad Z_3 = Z'_{S2} = 70.7\,\Omega, \quad Z_{S1} = Z'_{S3} = 50\,\Omega$$
$$Z'_{S1} = 100\,\Omega, \quad Z_{S3} = 25\,\Omega, \quad R_1 = 70.7\,\Omega, \quad R_2 = 141\,\Omega$$

Similarly, a power dividing ratio $K^2 = 4\,(P_2 = 4P_3)$ will require the characteristic impedances of the divider to be:

$$Z_2 = Z_{S2} = 25\,\Omega, \quad Z_3 = Z'_{S2} = 100\,\Omega, \quad Z_{S1} = 35.4, \quad Z'_{S1} = 141\,\Omega$$
$$Z_{S3} = 17.7, \quad Z'_{S3} = 70.7\,\Omega, \quad R_1 = 50\,\Omega, \quad R_2 = 200\,\Omega$$

To verify the performance of the proposed unequal divider, two power dividers with different power dividing ratios, $K^2 = 2$ and $K^2 = 4$, are designed. The designed centre frequency is fixed at 1.5 GHz, and the relative dielectric permittivity of the substrate is chosen 2.65 with thickness of 1 mm. The physical dimensions of the unequal dividers after optimization are listed in Table 2.

A photograph of the fabricated patch type power divider with power dividing ratios 2:1 is shown in Figure 7. The simulation is realized using Ansoft's HFSS and measurement is carried out using Agilent network analyzer N5230A. Figure 8 gives the simulated and measured results of the power divider. It can be observed that the operating bandwidth of this power divider is about 60% with the −15 dB input return loss criteria keeps in mind. The insertion loss of the patch type power divider is 0.3 dB for the simulation and 0.4 dB for the measurement. The difference of the insertion loss between simulated and measurement is caused by SMA connector while slight shift in frequency between simulations and measurements is attributed to the instability of the used material and the fabrication tolerances.

Table 2. Physical dimensions of the unequal dividers after optimization (unit: mm).

	Z_2	Z_3	Z_{S1}	Z_{S2}	Z_{S3}	Z'_{S1}	Z'_{S2}	Z'_{S3}	R_1	R_2
$K^2 = 2$	3.7	2	1.5	0.2	2	0.5	0.7	0.8	85 Ω	115 Ω
$K^2 = 4$	4	2	1.6	−0.25	1.7	−0.1	0.9	−0.1	85 Ω	120 Ω

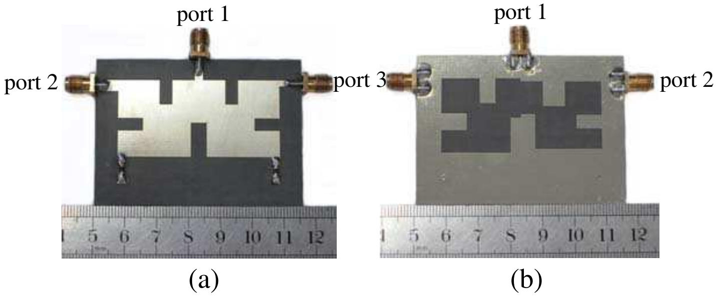


Figure 7. Photograph of the proposed 2:1 power divider. (a) Top view. (b) Bottom view.

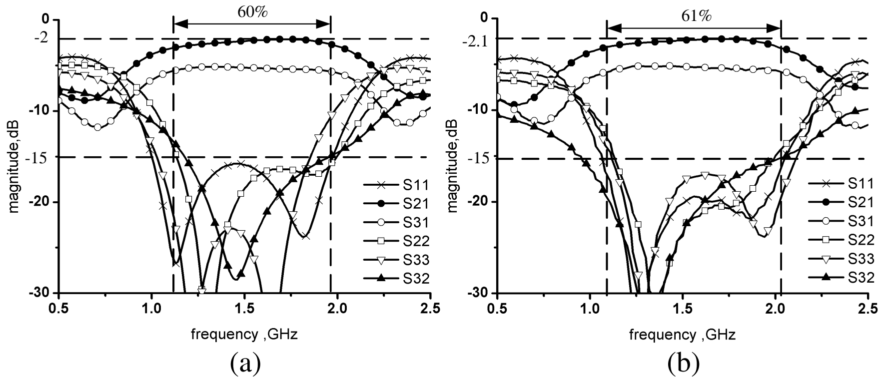


Figure 8. Simulated and measured results of proposed 2:1 power divider power divider. (a) Simulated results. (b) Measured results.

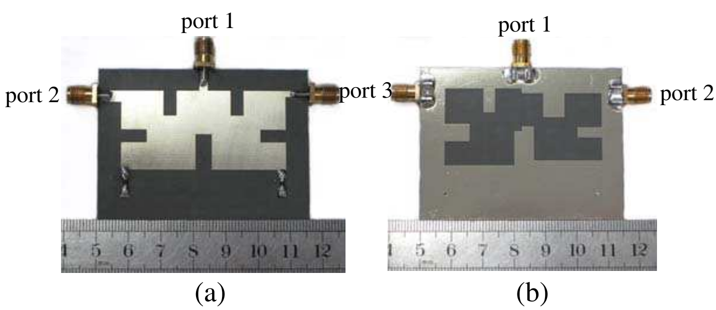


Figure 9. Photograph of the proposed 4:1 power divider. (a) Top view. (b) Bottom view.

Figure 9 shows a photograph of the fabricated unequal divider with the power dividing ratio 4:1. The simulated results using Ansoft's HFSS and measured S-parameters using Agilent network analyzer N5230A are shown in Figure 10. As can be observed from the results, the insertion loss of the proposed power divider is less than 0.5 dB, while the operating bandwidth of this power divider is up to 60%, with return losses of input and output ports lower than −15 dB. The results between measured and simulated agree well with each other.

From the equal and unequal power divider design procedure it can be concluded that the proposed patch type power divider performs well in equal and unequal power dividing. Besides, it is noteworthy that the fabricated power divider shows excellent stability when it is under test. Dues to the centro-symmetric electric field lines distribution

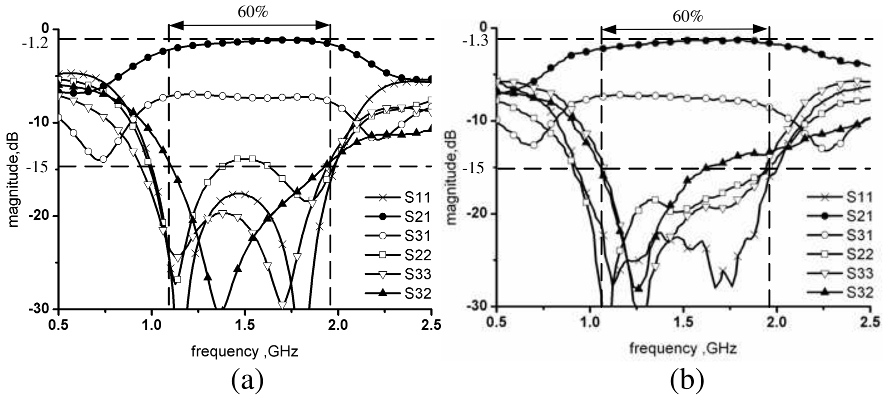


Figure 10. Simulated and measured results of proposed 4:1 power divider power divider. (a) Simulated results. (b) Measured results.

of this patch type structure, the complex surrounding environment contributes little affects to its performance, which means the proposed patch type power divider can be used in high power application as well as in systems with complex electromagnetic environment.

4. CONCLUSION

A novel patch type Gysel power divider which is different from the conventional microstrip configuration is presented in this paper. More than 30% bandwidth enhancement is provided while 55% size reduction is achieved compared with the conventional Gysel power divider. Flat dividing is obtained in the power divider. Based on the patch type structure, a design procedure with unequal power dividing ratios of 2:1 and 4:1 is provided without using narrow microstrip line, which makes it easier to design and fabricate extremely unequal power divider. The proposed dividers are manufactured and measured for demonstration purposes, and good agreement between simulated and measured results is observed.

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