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A 6 : 1 UNEQUAL WILKINSON POWER DIVIDER WITH EBG CPW

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Abstract—A 6 : 1 unequal Wilkinson power divider that combines the advantages of a coplanar waveguide with an electromagnetic bandgap (EBG CPW) and microstrip line structures suitable for a PCB circuit design is proposed. The highly characteristic impedance transmission line (TL) is realized by employing the proposed EBG CPW structure, which is difficultly achieved using the conventional microstrip line or CPW due to printed circuit board (PCB) process limitations. The proposed EBG structure enables the CPW line to have a very high characteristic impedance of over 207 Ω. The fabricated 6 : 1 power divider delivers excellent matching and isolation performances with more than 34 dB at 1.5 GHz. It also has exact dividing ratios of 8.46 dB and 0.7 dB at two output ports, respectively.

1. INTRODUCTION

Power dividers are widely used in various microwave communications and high frequency applications. The standard Wilkinson power divider for an even number of two or more output signals was first presented by Wilkinson in 1960 [1]. Up to now, many new power dividers are still being proposed [2, 3]. These can reduce the dimensions of the divider. The proposed dividers have an equal power

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dividing ratio. In contrast, for the divider with highly unequal power ratios, a microstrip line having very high characteristic impedance is required [4]. For instance, the 6 : 1 power divider requires a 207 Ω microstrip line. In order to enhance the microstrip line impedance, it needs to employ a narrow microstrip trace that eventually leads to a reduction of its power handling capability and an increase of its insertion loss. Moreover, the narrow strip width cannot be easily fabricated in a conventional PCB process.

Some studies have been reported to overcome this problem [4–7]. In the work [5], the microstrip line with a meander-shaped defected ground structure (DGS) pattern was proposed to increase the realizable line impedance by increasing the equivalent inductance. However, the increase of the impedance is limited due to the enhanced parasitic capacitance combined with an increase in the equivalent inductance. More recently, the microstrip line with rectangular-shaped DGS patterns and the rectangular-shaped DGS with an island in the middle of DGS were proposed in [4, 6]. However, these methods are neither uniplanar nor truly one-dimensional (1-D) structures because their defected ground planes are on the backside of substrate. Moreover, the DGS patterns should be kept far from the other conductors of the ground plane. Thus, the design procedure is relatively complex, inducing a degraded manufacturing yield. To avoid these drawbacks, a coplanar waveguide with electromagnetic bandgap structures for microwave integrated circuits (MIC's) was proposed to design a transmission line with high characteristic impedance [7]. It is a pity that the design needs extra bonding wires in order to remove other modes, except for the CPW mode which requires extra cost and also suffers extra yield loss. Bonding a wire makes the process more complex and the manufacturing cost higher.

In this paper, an EBG CPW structure is described in detail and applied in the design of a 6 : 1 unequal Wilkinson power divider. The proposed EBG CPW structure with a wider strip width can accomplish high characteristic impedance. Furthermore, the proposed unequal Wilkinson power divider also performs true 1-D structures by incorporating the EBG CPW and microstrip line structures without any bonding wire.

2. CIRCUIT LAYOUT AND ANALYSIS

The topology of a 6 : 1 unequal Wilkinson power divider is illustrated in Fig. 1, including the required characteristic impedance, isolation resistor, and termination impedances. The input power is split unequally and outputted at the two output ports. The two output

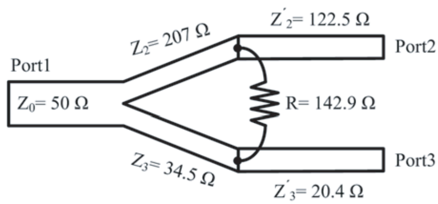


Figure 1. Topology of a 6 : 1 unequal Wilkinson power divider including its parameters.

signals present a 0° phase difference. The 6 : 1 power divider requires a 207 Ω microstrip line, which is difficult to realize due to PCB process limitations.

The configuration of the proposed divider is illustrated in Fig. 2, which consists of the EBG CPW and microstrip line structures. The design concept of the circuit uses a CPW with EBG structures to realize the highly characteristic impedance of Z_2, and the ground planes can be connected to each other using via holes, thus avoiding the undesired waveguide modes generated. The EBG structure is symmetrically etched on both sides of the ground planes of the CPW. The characteristic impedance of the proposed EBG CPW structure can be evaluated by several design parameters as shown in Fig. 2, namely: 1) the slot gap (g); 2) the rectangular region (h and b); and 3) the separation between the rectangle and the edge of the ground (d).

The analysis of the proposed EBG CPW structure is done using the Zeland IE3D EM software to evaluate the characteristic impedances of Z_2. The simplified transmission line model for determining the characteristic impedance (Z_2) of the proposed EBG CPW is depicted in Fig. 3, where the effective length of the EBG CPW is designed to be a quarter-wavelength at 1.5 GHz [5]. The maximum reflection coefficient (S_{11}) is used for calculating the characteristic impedance of a transmission line. The characteristic impedance (Z_2) can be calculated using Equations (1) to (3).

$$S_{11}\,[\mathrm{dB}] = 20 \log |\Gamma| \tag{1}$$

$$Z_{in} = Z_0 \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2}$$

$$Z_2 = \sqrt{Z_{in} Z_0} = Z_0 \sqrt{\frac{1+|\Gamma|}{1-|\Gamma|}} \tag{3}$$

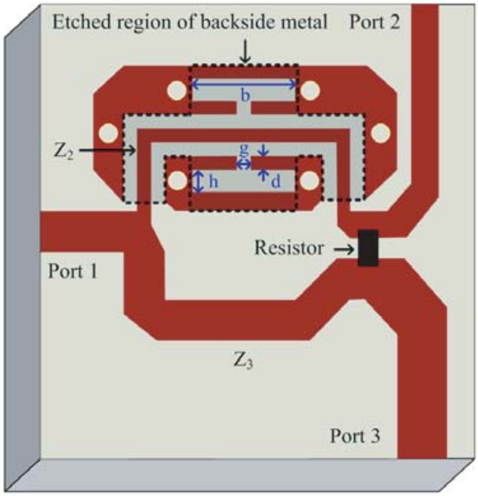


Figure 2. A schematic diagram of the proposed 6 : 1 unequal Wilkinson power divider.

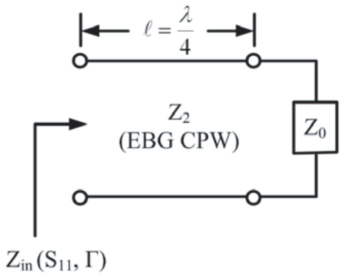


Figure 3. Simplified model to determine the characteristic impedance (Z_2) of EBG CPW.

The simulated results of the reflection coefficient (S_{11}) of the EBG CPW by varying the design parameters (h, b, and d) are plotted in Fig. 4, where the frequency and the slot gap (g) are equal to 1.5 GHz and 0.3 mm, respectively. It is observed that the main design parameters for increasing the characteristic impedance of the CPW are the rectangular regions (h and b). The characteristic impedance can be enhanced by increasing the parameters of h and b and decreasing the parameter of d. Thus, after calculating using Equations (1) to (3) and checking Fig. 4, the EBG CPW dimensions for a 207 Ω line could be found. The parameters are shown as follows: $G/W/G$ is 2/0.55/2 mm, where W is the width of the center line and G is the gap of the CPW, g is 0.3 mm, d is 0.8 mm, b is 13.7 mm, and h is 5.4 mm. The simulated S_{11} of the EBG CPW is equal to -1.01 dB at 1.5 GHz as shown in Fig. 5, corresponding to a characteristic impedance of 207 Ω.

A comparison of the 6 : 1 unequal Wilkinson power divider with the different transmission lines is summarized in Table 1. As shown in the table, the EBG CPW presents a significant strip width improvement to achieve high characteristic impedance as compared with other standard microstrip lines.

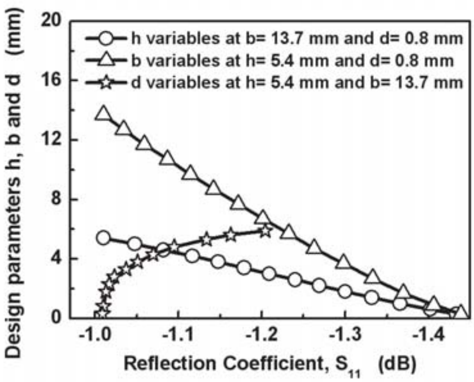


Figure 4. Reflection coefficient (S_{11}) of EBG CPW by varying the design parameters (h, b, and d).

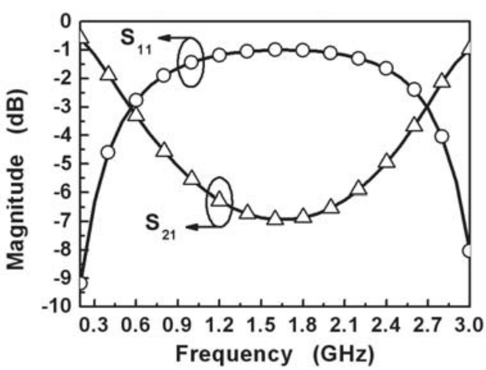


Figure 5. Electromagnetically calculated S-parameter of the proposed EBG CPW.

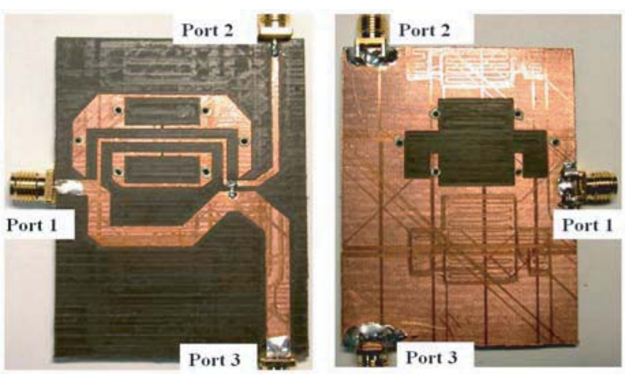
Table 1. Comparison of the different transmission line.

Type	Impedance	Strip Width	Spacing of CPW
Conventional microstrip line	207 Ω	0.085 mm	—
CPW line	207 Ω	0.28 mm	2 mm
Proposed CPW with the EBG	207 Ω	0.55 mm	2 mm

3. IMPLEMENTATION AND PERFORMANCE

To validate the design structure, a Rogers RT/Duroid 5880 with a relative permittivity of 2.2 and a 31 mil-thick substrate was used to implement the 6 : 1 unequal Wilkinson power divider at the center frequency of 1.5 GHz. A photograph of the fabricated power divider, which has the 207 Ω CPW line with the EBG structure, is shown in Fig. 6.

The optimal dimensions are optimized using the Zeland IE3D EM software, which is considered to be a good simulator for microwave circuits, in order to obtain the exact dividing ratios. The final dimensions of the proposed EBG CPW structure are found and implemented as follows: $g = 0.3$ mm, $d = 0.8$ mm, $b = 13.7$ mm, $h = 5.4$ mm, $G/W/G = 2/0.55/2$ mm, and length = 38.4 mm. An isolation resistor equal to 150 Ω is selected instead of one equal to



(a) (b)

Figure 6. Photograph of the fabricated 6 : 1 Wilkinson power divider (a) top side, (b) bottom side.

142.9 Ω due to the unavailability of a precise resistor value. To validate the design, the proposed power divider was measured using an Agilent PNA E8364A network analyzer. A thru-reflect-line (TRL) calibration method was used to de-embed the S-parameters of the divider from the measured data. The simulated and measured results of insertion loss, isolation, and return loss are plotted in Figs. 7 and 8.

From the measured results, the S_{21} and S_{31} are approximately 8.46 dB and 0.7 dB at 1.5 GHz, respectively. The measured isolation between port 2 and port 3 is also better than 38.6 dB. It shows that the two output ports have good isolation from each other. The measured return losses are better than 34 dB at 1.5 GHz. Some discrepancies between the simulation and the measurement can be observed in Figs. 7 and 8 due to the unexpected tolerance of fabrication and assembly.

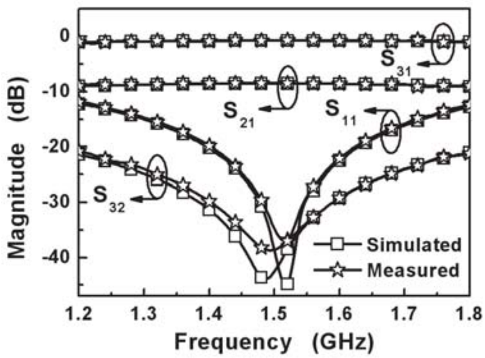


Figure 7. The simulated and measured results of the insertion loss, isolation, and input return loss as a function of frequency.

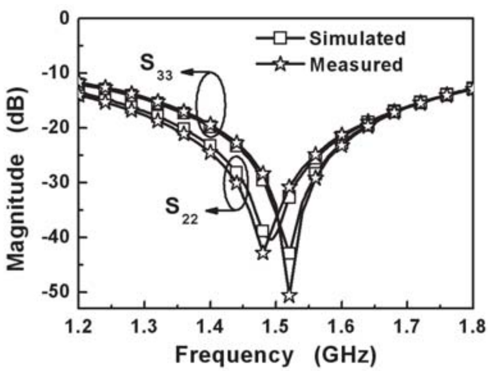


Figure 8. The simulated and measured results of the output return loss as a function of frequency.

Comparisons of the proposed divider with the other published unequal Wilkinson power dividers are summarized in Table 2. The proposed divider exhibits a wider strip width for the characteristic impedance of 207 Ω while maintaining highly unequal power ratios. In addition, it is not necessary to use backside patterns and extra bonding wires, thus enhancing the manufacturing yield.

Table 2. Comparison of the unequal Wilkinson power dividers.

<table>
<tr><td colspan="2">Ref.</td><td>This Work</td><td>[4]</td><td>[5]</td><td>[6]</td><td>[7]</td></tr>
<tr><td colspan="2">Substrate Material and Thickness</td><td colspan="4">RT/Duroid 5880
31 mils</td><td>GaAs
625 μm</td></tr>
<tr><td colspan="2">Frequency</td><td colspan="4">1.5 GHz</td><td>3.5~5.5 GHz</td></tr>
<tr><td colspan="2">Power Dividing Ratio</td><td>1 : 6</td><td>1 : 6</td><td>1 : 4</td><td>1 : 6</td><td>1 : 3</td></tr>
<tr><td rowspan="2">TL</td><td>Type</td><td>CPW with EBG</td><td>TL with DGS</td><td>TL with DGS</td><td>TL with DGS and island</td><td>CPW with EBG</td></tr>
<tr><td>Impedance</td><td>207 Ω</td><td>207 Ω</td><td>158 Ω</td><td>207 Ω</td><td>132 Ω</td></tr>
<tr><td colspan="2">Strip Width</td><td>0.55 mm</td><td>0.4 mm</td><td>0.4 mm</td><td>0.4 mm</td><td>10 μm</td></tr>
<tr><td colspan="2">Bonding Wires</td><td>None</td><td>None</td><td>None</td><td>None</td><td>Needed</td></tr>
<tr><td colspan="2">Backside Patterns</td><td>None</td><td>Needed</td><td>Needed</td><td>Needed</td><td>None</td></tr>
</table>

4. CONCLUSION

A 6 : 1 unequal Wilkinson power divider with EBG CPW structure has been proposed and implemented. The proposed EBG CPW structure eliminates the main difficulty of a narrow strip width of a 6 : 1 unequal power divider. The fabricated conductor width of the 207 Ω transmission line was 0.55 mm, 0.085 mm for the conventional microstrip line, and 0.28 mm for the CPW in EM simulation. The proposed EBG structure enabled the CPW with very high characteristic impedance to be easily designed on PCB without using the backside patterns and extra bonding wires. On the other hand, additional processes are not needed when using the proposed structures. The proposed technique can be widely used in many RF and microwave circuits to provide more desirable flexibility.

ACKNOWLEDGMENT

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