Wideband power divider using Gysel and modified Wilkinson structure

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Abstract: A novel two-way power divider (PD) with wideband frequency response is presented in the paper. By combining a Gysel and a modified Wilkinson power divider, the proposed PD achieves a balance between heat-handling and bandwidth. Owing to its symmetrical structure, the operating mechanism can be derived by the even- and odd-mode analysis. Then, a prototype of an in-phase power divider operating at 3.75 GHz has been designed, fabricated and measured. The measured results demonstrate an acceptable bandwidth of about 72\% with isolation $>15$ dB and return loss $>14$ dB.

Keywords: power divider, Gysel, Wilkinson, wideband, bandwidth

Classification: Microwave and millimeter-wave devices, circuits, and modules

References


1 Introduction

The power divider (PD) is an essential passive component in the modern communication systems [1]. According to the operating power values, power divider can be classified into two typical types. One of the topologies is Wilkinson power divider, which is firstly proposed in [2]. Due to its advantages of simplicity and acceptable bandwidth, equal and unequal power division are investigated [3, 4, 5]. Using two-section asymmetrical T-structures and multiple coupled line, the PD in [3, 4] achieve significant size reduction, respectively. In [5], a modified Wilkinson PD with two inductors exhibits good harmonic suppression and arbitrary power division ratio. However, the resistor between the output ports is not grounded, Wilkinson PD suffers from poor heat-handling. By introducing two short-ended resistors, Gysel PD could transfer heat to the ground and achieve high power-handling [6, 7]. But the narrow bandwidth of about 30% limits its application.

Recently, great efforts have been made to improve the bandwidth of Gysel PD [8, 9, 10, 11]. By reducing one resistor and introducing suitable transmission lines, the PD in [8] shows broadband response with isolation better than 15 dB. In addition, a novel Gysel power divider adds about 35% bandwidth based on coupled lines [9]. Furthermore, the 15-dB isolation bandwidth of two-way PD has increased from 30% to 62% using multistage technology [10, 11].

In this paper, a planar wideband power divider by combining Gysel and modified Wilkinson structure is reported. Thus, the proposed PD could find a balance between heat-handling and bandwidth. Moreover, the values of parameters can be derived through odd- and even-mode analysis. Finally, a prototype of proposed power divider centered at 3.75 GHz is designed. The measured results depict that the acceptable bandwidth is about 72% with isolation better than 15 dB.

2 Analysis and design of the power divider

The whole topology of proposed power divider is shown in Fig. 1(a). It consists of conventional Gysel and modified Wilkinson structures with four-type transmission lines (Z₁ – Z₄) and three isolation resistors (R₁, R₂). Thus, the proposed PD could combine the advantages of heat-handling and bandwidth. The odd- and even-mode analysis is employed to determine those parameters (Z₁, Z₂, Z₃, Z₄, R₁, and R₂). For traditional Gysel power divider, the electrical lengths are set as θ₁ = θ₂ = θ₃ = 90° (at the center-frequency).
Fig. 1(b) shows the equivalent circuit of proposed power divider under odd-mode excitation at ports 2 and 3. The symmetrical plane in Fig. 1(a) will behave as an electric-wall. Thus, the impedance of port 1 is doubled and isolation resistor $R_2$ becomes virtual grounded $R_2 = \frac{2}{Z_0}$.

The relations of admittances can be derived as

$$Y_{\text{odd}} = Y_{\text{odd}'} + Y_{\text{odd}''} = 2G_2 + Y_4 - jY_2 \cot \theta_4 / G_1$$

(1)

where $Y = 1/Z$ and $G = 1/R$. For modified Wilkinson structure, we set $\theta = 270^\circ$. To achieve good impedance matching, the admittance $Y_{\text{odd}}$ is simply equal to $Y_0$.

Thus,

$$Y_{\text{odd}} = 2G_2 + G_1 \frac{Y_4^2}{Z_4^2} = Y_0$$

(2)

When ports 2 and 3 are excited by even mode, the centre vertical plane acts a magnetic-wall Fig. 1(c). Similarly, the impedance of port 1 is doubled and isolation resistor $R_2$ becomes open-circuited $R_2 = \frac{2}{Z_0}$. The relations of admittances can be summarized

$$Y_{\text{even}} = Y_{\text{even}'} + Y_{\text{even}''} = 0 + Y_0^2 Y_0 / 2Y_4^2 = Y_0$$

(3)

Formula (2) and (3) present the admittance relations under good impedance matching at output ports. When $G_2 \rightarrow 0$, the proposed power divider becomes a conventional Gyssel PD. The layout of proposed power divider is shown in Fig. 2. $Z_r$ and $\theta_r$ are introduced to place $R_1$ properly. Then, we can choose $Z_1 = 70.7 \Omega$, $Z_2 = 50 \Omega$, $Z_4 = 50 \Omega$, $Z_r = 53.5 \Omega$, $R_1 = 100 \Omega$, $R_2 = 200 \Omega$, $\theta_1 = 82.22^\circ$, $\theta_2 = 103.1^\circ$, $\theta_3 = 83.69^\circ$, $\theta_4 = 274.5^\circ$, and $\theta_r = 48.5^\circ$. And from the reference [6], the initial value of $Z_3$ is set as $50 / \sqrt{2} = 35 \Omega$ for a wide bandwidth performance.
Fig. 3 depicts the simulated S-parameters of $S_{21}$, $S_{22}$ and $S_{23}$. However, for a better isolation performance, the parameter are required to be adjusted properly. Finally, the design parameters of proposed power divider are optimized as follows: $Z_1 = 71.68 \, \Omega$, $Z_2 = 82.52 \, \Omega$, $Z_3 = 24.78 \, \Omega$, $Z_4 = 41.86 \, \Omega$, $Z_r = 53.5 \, \Omega$, $R_1 = 68 \, \Omega$, $R_2 = 150 \, \Omega$, $\theta_1 = 82.17^\circ$, $\theta_2 = 100.36^\circ$, $\theta_3 = 83.69^\circ$, $\theta_4 = 276.5^\circ$, and $\theta_r = 48.5^\circ$.

Fig. 4 shows the simulated $S_{21}$ with varied $R_1$. With the increasing of $R_1$, the acceptable bandwidth is improved while less current flows through $R_1$ [5]. Thus, less heat could be transferred to the ground. Obviously, there is a trade-off between bandwidth and heat-handling. In Fig. 5, the $Z_r$ and $\theta_r$ have little impact on the results, which will not affect the design process above.
3 Experimental results

In this section, one example power divider operating at 3.75 GHz has been fabricated and measured. A Rogers5880 substrate with a relative dielectric constant of 2.2 and a thickness of 0.508 mm is chosen. Simulation is accomplished using an electromagnetic (EM) simulator HFSS 15.0 and measurement is carried out on an Agilent E8363B network analyser. Fig. 6 shows the photograph of fabricated power divider. The bent microstrip lines are applied to reduce the circuit size.

The simulated and measured S-parameters of the developed PD are shown in Fig. 7. As can be seen, the input power is equally divided between the two output ports and the measured $|S_{21}|$ and $|S_{31}|$ are within $3.6 \pm 0.5$ dB in the passband. Moreover, the maximum amplitude imbalance between the power levels at the two output ports is around 0.8 dB. The measured isolation is better than 15 dB from 2.4 to 6 GHz.

![Fig. 5. Simulated results with and without $Z_r$ and $\theta_r$.](image)

![Fig. 6. Photograph of fabricated power divider.](image)

![Fig. 7. Simulated and measured S-parameters of proposed PD; solid lines represent measurements.](image)
to 5.1 GHz with a 72% fractional bandwidth, while the return loss is greater than 14 dB over the same frequency range. Table I lists comparisons with some reported power dividers. It is clearly noted that the proposed PD has the advantage of wide bandwidth.

<table>
<thead>
<tr>
<th>Ref</th>
<th>Fractional bandwidth (%)</th>
<th>Isolation (dB)</th>
<th>Return Loss (dB)</th>
<th>Topology type</th>
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<td>[4]</td>
<td>58.8</td>
<td>&gt;9</td>
<td>Not given</td>
<td>Wilkinson</td>
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<td>[7]</td>
<td>30</td>
<td>&gt;15</td>
<td>&gt;15</td>
<td>Gysel</td>
</tr>
<tr>
<td>[9]</td>
<td>65</td>
<td>&gt;15</td>
<td>&gt;15</td>
<td>Gysel</td>
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<tr>
<td>This work</td>
<td>72</td>
<td>&gt;15</td>
<td>&gt;14</td>
<td>Gysel&amp;Wilkinson</td>
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</table>

4 Conclusion

In this letter, a novel wideband power divider by combining Gysel and Wilkinson structures is presented. Compared with conventional Wilkinson PD, the proposed PD achieves a better heat-handling. Meanwhile, it also adds about 42% bandwidth against conventional Gysel topology. Thus the proposed PD combines the advantages of bandwidth and power-handling. Moreover, the measured results are in good agreement with simulated ones. It could be a good candidate for modern wireless communication systems.