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Wideband Gysel HMSIW power divider with high power-handling capability

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Research Paper

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Abstract

A novel Gysel power divider with high power-handling capability based on half-mode substrate integrated waveguide (HMSIW) has been presented in this paper. A HMSIW ring is used and good input/output impedance matching is achieved based on HMSIW-microstrip taper transition. Two microstrip stubs are introduced in HMSIW ring to assemble two isolation resistors to improve the isolation between the output ports. The even- and odd-mode analysis method is used for the presented circuit. A prototype of the presented power divider is designed, fabricated, and measured. The measured results show a reasonable agreement with the simulated ones.

Introduction

The power divider is one of the key passive components in power combining amplifiers and antenna arrays. Traditional Wilkinson power divider is widely used in microwave and millimeter-wave systems because of its simple structure, easy to design, and good isolation. However, the heat dissipation of the isolation resistor is a major issue for high-power applications because the isolation resistor is not grounded. It is well known that the Gysel power dividers [1–11] have the high power-handling capability by introducing two short-circuited resistors that can transfer the heat to the ground plane effectively. In the past decades, more attention have been focused on the Gysel power dividers with different functions, such as multi-band [2–5], wideband [6, 7], bandpass filtering response [8, 9], and arbitrary power division ratio [10].

On the other hand, the high heat will generate in the transmission lines of the traditional Gysel power dividers (see Fig. 1(a)) under the condition of high input power, which cannot be removed rapidly and effectively because of the small radiating area of the microstrip transmission lines and the lack of effective heat sinking. Then, the thin microstrip transmission lines (in general the thin copper is used) will be seriously oxygenated and burned down by the high heat.

The substrate integrated waveguides (SIWs) are developed as an attractive technique for low loss, low cost, high power-handling capability, and high-density integration. Half mode SIW (HMSIW) is a type of miniaturized SIW [12]. Several SIW and HMSIW power dividers have been studied in [13–18] and some good performances such as low loss, high power-handling capability, and easy integration are reported.

In this paper, a novel wideband Gysel HMSIW power divider with high power-handling capability has been developed. The presented circuit is achieved based on a HMSIW ring, while two grounded isolation resistors are used to realize good isolation between output ports. Moreover, its good performance has been demonstrated experimentally of compact size, high isolation, and good input/output impedance matching.

Design and analysis of the proposed power divider

Figure 1(b) shows the presented Gysel HMSIW power divider. It consists of a HMSIW ring, three HMSIW-microstrip gradual taper transitions, and two microstrip stubs to assemble two isolation resistors. It is obvious that the heat of the transmission lines can be radiated to the atmosphere rapidly and effectively because of the large radiating area, and removed to the ground plane (heat sinking) through the via holes. Then, compared with the traditional microstrip Gysel power dividers, the relative low temperature of the presented HMSIW Gysel power dividers can be kept under the condition of high input power (such as more than 100 W).

Good impedance matching can be implemented by using the HMSIW–microstrip taper transitions. The length between the input port and the output port are chosen to λg/4 (λg is the guided wavelength of HMSIW at the center frequency), while the HMSIW ring's length between two isolation resistors is λg/2. Moreover, the length of the two microstrip stubs L1 is

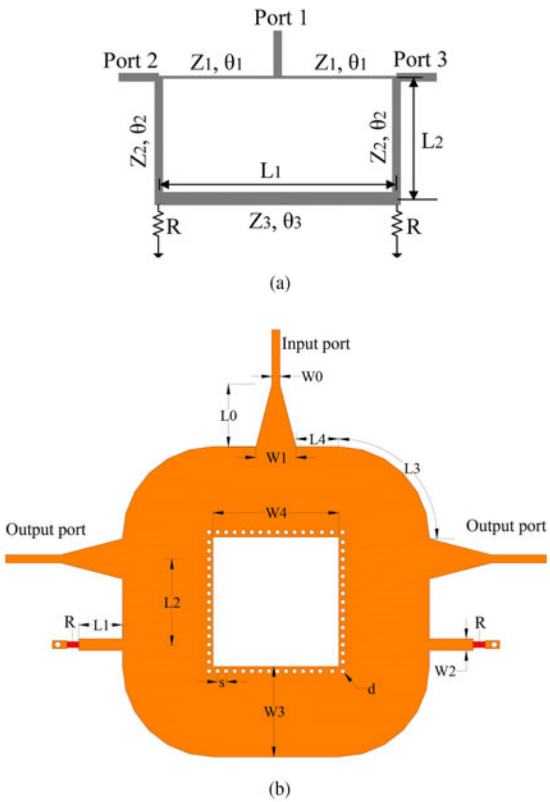

Fig. 1. (a) Conventional and (b) presented Gysel power divider.

also chosen to be λg/4 to achieve the impedance matching between the HMSIW ring and the isolation resistors. The even- and odd-mode analysis method can be applied to analyze and design the presented Gysel HMSIW power divider due to the circuit symmetry. If two signals of same amplitude and in phase (even mode) are applied at two output port, by symmetry a voltage maximum occurs at every point on the line of symmetry. That is, at these points $Z = \infty$. This is the equivalent of an open circuit as illustrated in Fig. 2(a) and the *O, C* represent open circuit. Similarly, if two signals of same amplitude and out of phase (odd mode) are applied at two output port, a voltage minimum occurs at every point on the line symmetry. That is, at these point $Z = 0$. This is the equivalent of a short circuit as illustrated in Fig. 2(b) and the short circuit is grounded.

The even and odd mode analysis can simplify the circuit. With even mode excitation and odd mode excitation, the simplified circuit can be analyzed, respectively. Figure 2(a) shows the even-mode circuit model for a bisection of this power divider. Firstly, it gives the impedance/admittance analysis of the parts of the even mode circuit. The input impedance is Z_0, as for a bisection of input post, the input impedance is $2Z_0$. It is the same as micro taper which is $2Z_T(x)$ in the even mode circuit. The characteristic impedance $Z_T(x)$ of the microstrip taper can be given by

$$Z_T(x) = \frac{120\pi/\sqrt{\varepsilon_e}}{w(x)/d + 1.393 + 0.667\ln[w(x)/d + 1.444]}, \quad (1)$$

where $w(x) = [x(w_1 - w_0) + w_0 L_0]/L_0$ and x is the position along the taper. So the reflection coefficient and the input admittance

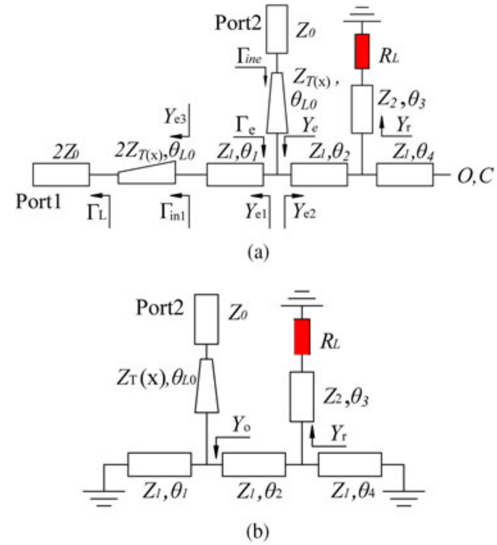

Fig. 2. Even- and odd-mode equivalent circuit of the presented power divider: (a) even mode, (b) odd mode.

of the gradual taper at $x = L_0$ is given by

$$\Gamma_{\text{in1}} = \frac{1}{2}\int_0^{L_0} e^{-j2\beta x}\frac{d[\ln 2Z_T(x)]}{dx}dx + \Gamma_L, \quad (2)$$

$$Y_{e3} = \frac{1 - \Gamma_{\text{in1}}}{(1 + \Gamma_{\text{in1}})2Z_T(L_0)}. \quad (3)$$

The total input admittance Y_e can be expressed as

$$Y_e = Y_{e1} + Y_{e2}, \quad (4)$$

where

$$Y_{e1} = Y_1(Y_{e3} + jY_1 \tan\theta_1)/(Y_1 + jY_{e3}\tan\theta_1), \quad (5)$$

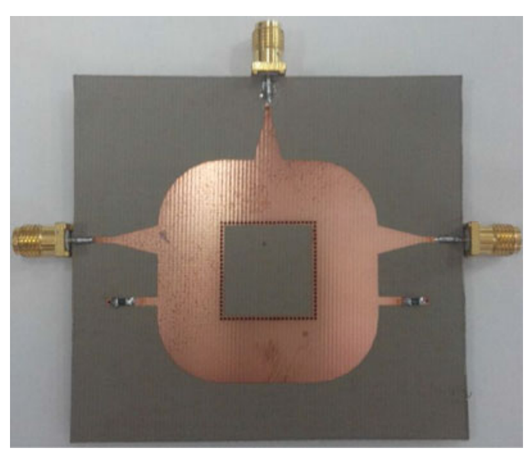

Fig. 3. Photograph of the fabricated power divider.

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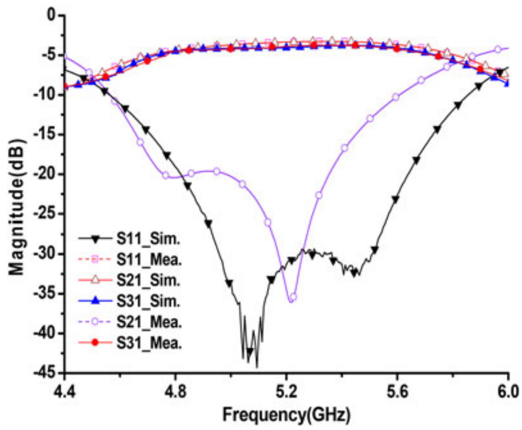

Fig. 4. Simulated and measured input return loss and insertion loss.

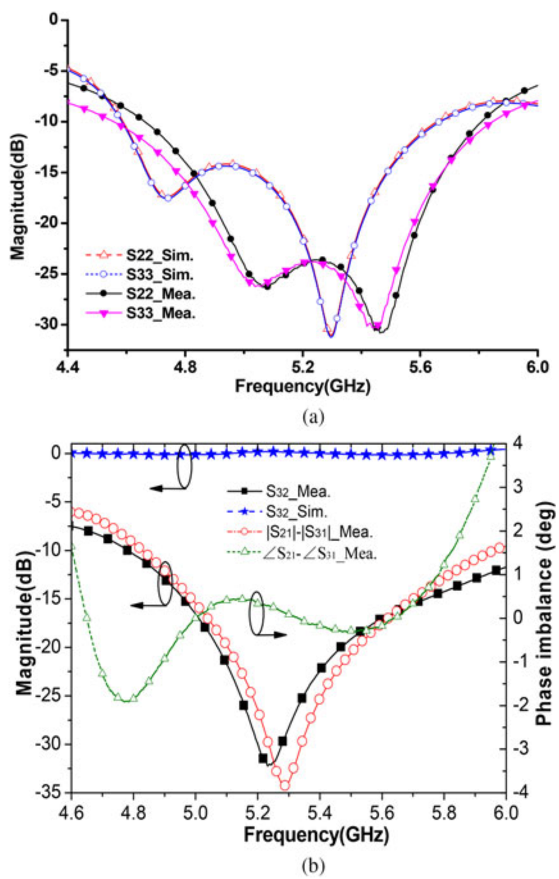

Fig. 5. Simulated and measured results: (a) output return loss and Photograph of the fabricated power divider, (b) isolation, magnitude, and phase imbalance.

$$Y_{e2} = Y_1 \frac{Y_r + jY_1(\tan\theta_2 + \tan\theta_4)}{Y_1 + j(Y_r + jY_1\tan\theta_4)\tan\theta_2}, \tag{6}$$

where Y_1 is the characteristic admittance of HMSIW and

$$Y_r = \frac{Z_2 + jR_L\tan\theta_3}{Z_2(R_L + jZ_2\tan\theta_3)}. \tag{7}$$

Moreover, the reflection coefficient Γ_e can be given by

$$\Gamma_e = (1 - Y_e Z_T(w_1))/(1 + Y_e Z_T(w_1)). \tag{8}$$

The input reflection coefficient Γ_{ine} at port 2 can be given by

$$\Gamma_{\text{ine}} = \frac{1}{2}\int_0^{L_0} e^{-j2\beta x}\frac{d[\ln Z_T(\mathrm{x})]}{dx}d\mathrm{x} + \Gamma_e, \tag{9}$$

with the help of the formulas above, the desired input reflection coefficient of the presented power divider can be analyzed and synthesized. For example, according to (9) and the circuit sizes can be determined under the desired circuit design parameters (such as central frequency, bandwidth, return loss, etc.).

Under the odd-mode excitation, a bisection of the power divider is shown in Fig. 2(b). The input admittance Y_o can also be expressed by

$$Y_o = Y_1 \frac{Y_r + jY_1(\tan\theta_2 - \cot\theta_4)}{Y_1 + j(Y_r - jY_1\cot\theta_4)\tan\theta_2} - Y_1\cot\theta_1. \tag{10}$$

When $\theta_1 = \theta_2 = \theta_4 = \pi/2, Y_e = Y_o = 1/Z_T(w_1)$, good impedance matching can be achieved, and (4) and (10) can be reduced as

$$Z_1 = \sqrt{2}Z_T(w1), \tag{11}$$

$$R_L = Z_2^2/Z, \tag{12}$$

where Z_1 is the characteristic impedance of HMSIW. Equations (11) and (12) provide a simple guideline in the selection of Z_1 and R_L.

The even and odd mode analysis gives rough design parameters of the power divider. Furthermore, the power divider needed to optimize by commercial simulation software accurately.

Experimental results

Based on the design procedure discussed above, a Gysel HMSIW power divider has been designed. The Taconic RF-35 substrate with a relative dielectric constant of 3.5, the thickness of 0.508 mm, loss tangent of 0.0018 is used. The commercial software HFSS is used for optimizing the proposed power divider. The

Table 1. Comparison with other HMSIW power dividers

Ref	Frequency (GHz)	Intput return loss (dB)	Isolation (dB)	Output return loss (dB)	Size (λ^2)
[14]	8–10.45	>10	>7	>6	3.55 × 1.14
[16]	18–35	>10	>10	>10	2.36 × 1.67
This work	4.8–5.6	>15	>15	>15	1.73 × 1.44

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photograph of the fabricated power divider is shown in Fig. 3. The final sizes of this circuit are (unit: mm): $L_0 = 8.5$, $L_1 = 6$, $L_2 = 11$, $L_3 = 19.5$, $L_4 = 5.85$, $s = 0.9$, $d = 0.5$, $W_0 = 1.11$, $W_1 = 4.5$, $W_2 = 1.6$, $W_3 = 12.4$, $W_4 = 17.2$, $R_L = 70\ \Omega$.

Figure 4 shows the measured and simulated input return loss and insertion loss of the fabricated HMSIW power divider. The simulated input return loss is greater than 15 dB from 4.65 to 5.45 GHz, while the measured one is greater than 15 dB from 4.7 to 5.7 GHz and greater than 25 dB in the frequency range of 4.9–5.56 GHz. The simulated 1-dB insertion loss bandwidth (the 3 dB power division loss is not included) is about 900 MHz (4.8–5.7 GHz), while the measured one is about 850 MHz (4.8–5.65 GHz). The measured minimum insertion loss is about 0.7 dB. Compared with the simulation results, the increased insertion loss is most likely attributed to the fabrication error and the loss of the SMA connectors, which are not included in the simulation model.

Figure 5(a) shows the simulated and measured output return losses. It can be seen that the simulated output return loss is greater than 14 dB from 4.65 to 5.5 GHz, while the measured one is greater than 15 dB from 4.8 to 5.65 GHz. Moreover, the measured isolation is greater than 15 dB in the frequency range of 4.95–5.75 GHz, as shown in Fig. 5(b). It can be seen that a measured maximum amplitude imbalance of ± 0.2 dB and a phase imbalance of $\pm 2°$ are observed from 4.6 to 5.8 GHz. Table 1. shows the comparison with other HMSIW power dividers in recent years. It demonstrates that this work has realized the better performance of isolation, input/output return loss, and compact size.

Conclusion

A novel Gysel HMSIW power divider has been presented in this letter. A HMSIW ring, three HMSIW–microstrip taper transitions, two microstrip stubs, and two isolation resistors have been applied to construct the presented Gysel power divider. The circuit structural sizes and parameters of the presented power divider can be obtained from the even- and odd-mode equivalent circuit analysis. Reasonable agreement between simulated and measured results can be observed. The developed Gysel HMSIW power divider has many advantages, such as wide bandwidth, good input/output impedance matching, relatively high output isolation, and high power-handling capability. It can be applied for microwave and millimeter-wave systems.

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