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Filtering Power Divider/Combiner Based on Half Mode Substrate Integrated Waveguide (HMSIW) Technology for High Power Applications

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ABSTRACT

A filtering power divider/power combiner based on half mode substrate integrated waveguide technology for high power applications is proposed. This design includes one half mode substrate integrated waveguide cavity, one matched load, and four sections of quarter-wavelength transmission lines. The high isolation between output ports is obtained by combining the half mode substrate integrated waveguide cavity and microstrip network (one matched load and four sections of quarter-wavelength transmission lines). This structure utilizes for high power applications because of the matched load is connected to ground. The design is fabricated and tested by network analyzer. A good agreement between the simulated and measured results is observed. The measured results show that for a return loss of 15 dB, the bandwidth is from 5.15 to 5.35 GHz (IEEE 802.11a wireless local area network (WLAN) standard) and over this whole bandwidth, the output return loss and isolation between output ports are better than 14.5 dB and 17.5 dB, respectively. Also, the measured insertion loss is 4.4 ± 0.1dB.

KEYWORDS

Filtering Power Divider, Half Mode Substrate Integrated Waveguide (HMSIW), Power Combiner, Power Divider.

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1- INTRODUCTION

In millimeter-wave and microwave circuits, power dividers (PDs)/ power combiners (PCs) are one of the common and essential components. The traditional waveguide PD has the obstacles such as large size and integration with planar structures [1]. Recently, the substrate integrated waveguide (SIW) is introduced [2,3]. This structure is formed by two rows of metallic via holes in a planar substrate (as shown in Fig. 1) and has the advantages of low cost, low loss, high Q-factor, and most importantly small size and integration capabilities with planar circuits [4]. The half mode substrate integrated waveguide (HMSIW) has the all of them and also it has a smaller size than the SIW [5].

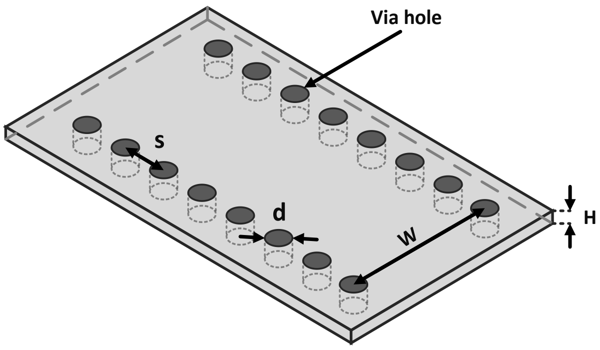

Fig.1. Configuration of a SIW structure.

The output matching and isolation are necessary to improve circuit performance. The Wilkinson PD [6] has been widely used in microwave circuits and systems because of good bandwidth, high isolation, low return loss and low insertion loss [7-9]. In this circuit, the resistors generate the heat dissipation due to they are not connected to ground. Moreover, the disruption in result is occurring due to the coupling output ports with each other in high frequency applications. Therefore, the Wilkinson PD utilizes for low power applications. As opposed to, the Gysel PD [10] is introduced for high power applications since the grounded resistors and heat transfer to ground.

Several SIW/HMSIW power dividers have been investigated [11-15]. Periodic butterfly radial slots power divider with enhanced out-of-band rejection had relatively large amplitude imbalance [11]. A broadband SIW T-junction with an arbitrary power-dividing ratio was presented [12]. This circuit had relatively large volume. SIW Y-junction power divider had comparatively large insertion loss [13]. In addition, these designs [11-13] did not have isolation between output ports. A compact SIW Wilkinson power divider and a broadband HMSIW Wilkinson power divider were introduced [14,15]. Due to the attached resistor, these structures were not proper for high power applications.

In this paper, a filtering PD/PC with high isolation for high power applications based on HMSIW and microstrip transmission lines is introduced. This PD/PC consists of one HMSIW cavity, one matched load, and four sections of quarter-wavelength transmission lines. The high isolation and high power applications is obtained because of the part of the Gysel PD is connected to the HMSIW cavity. Fig. 2 shows the building block of the proposed structure.

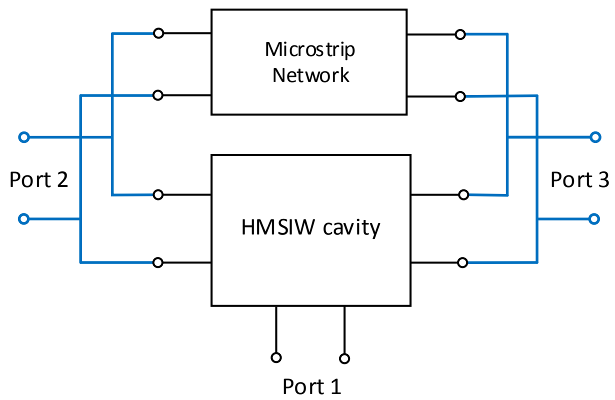

Fig.2. Building block of the proposed structure.

In this structure, the excited mode is TE_{101} mode. For design, an EM simulator and Rogers RO4003C substrate are used. This circuit is fabricated and the measured results are sampled by network analyzer.

A good agreement between the simulated and measured results is seen. For a return loss of 15 dB, the measured bandwidth is from 5.15 to 5.35 GHz (IEEE 802.11a WLAN standard). Fig. 3 displays the schematic of the proposed structure.

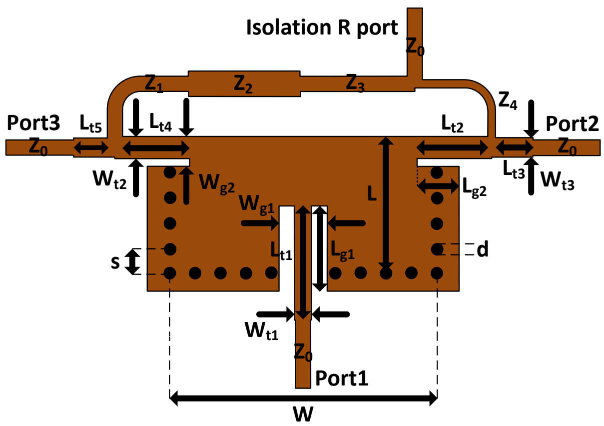

Fig.3. Schematic of the proposed structure.

2- GYSEL POWER DIVIDER

The Gysel PD is a cross between a branch line and a Wilkinson PD. Fig. 4 shows the conventional Gysel PD.

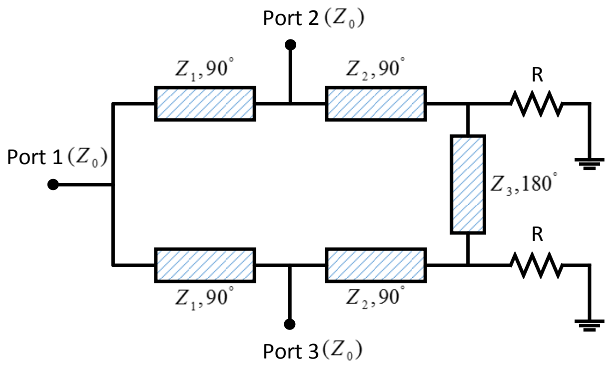

Fig.4. Configuration of the conventional Gysel PD.

This PD has the five ports and five branch-line sections with the characteristic impedances of $Z_2=Z_0=50$, $Z_1 = Z_0\sqrt{2}$, and $Z_3 = \frac{Z_0}{\sqrt{2}}$. In this section, the even and odd mode analyses are used to obtain the value of the characteristic impedances.

2-1- EVEN MODE

In the even mode, the potential at port 2 and port 3 should be of equal magnitude and phase. The equivalent circuit of this case is illustrated in Fig. 5.

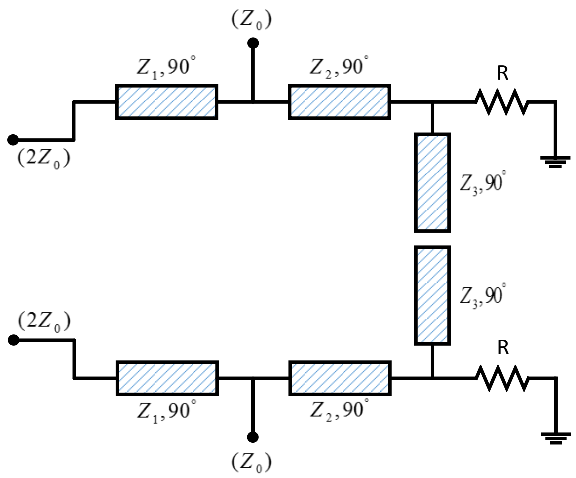

Fig.5. Equivalent even mode circuit of the conventional Gysel PD.

The simplified circuit of the Fig. 5 is shown in Fig. 6.

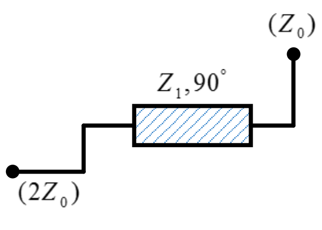

Fig.6. Simplified circuit of the Fig. 5.

As a result, the value of Z_1 is selected equal to $Z_0\sqrt{2}$.

2-2- ODD MODE

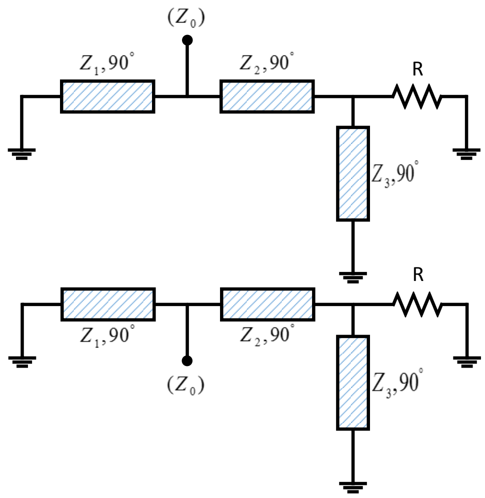

Fig.7. Equivalent odd mode circuit of the conventional Gysel PD.

In the odd mode, port 2 and port 3 are excited out of phase by 180 degrees. The equivalent circuit of this case is illustrated in Fig. 7. The simplified circuit of the Fig. 7 is shown in Fig. 8.

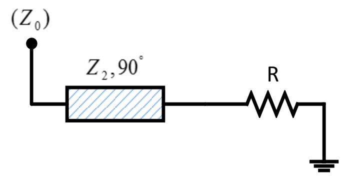

Fig.8. Simplified circuit of the Fig. 7.

In this case, R=50 and Z_2=50. Moreover, the value of Z_3 is does not care. The lowest impedance of Z_3 is equal maximum bandwidth. A Gysel PD is designed at the center frequency of 5.2 GHz and simulated by EM simulator. Fig. 9 depicts the results of this PD. This circuit has not a proper bandpass-filtering response.

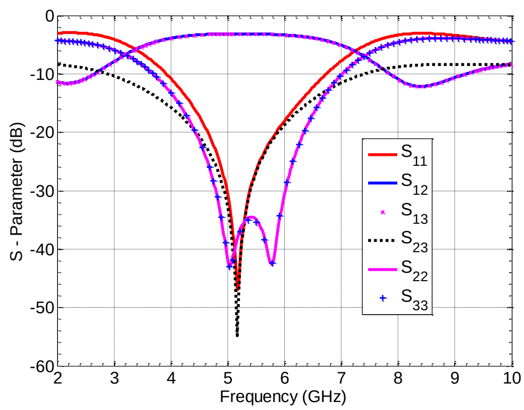

Fig.9. Results of the conventional Gysel PD.

3- DESIGN AND ANALYSIS

3-1- DESIGN PROCEDURE

In this structure, the excited mode is TE_{101} mode. For SIW cavity, the cutoff frequency is obtained by [16]:

$$f_{m0n} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m\pi}{W_{eff}}\right)^2 + \left(\frac{n\pi}{L_{eff}}\right)^2} \quad (1)$$

In (1), m and n are the mode indexes, c is the velocity of light in the free space, ε_r is the relative permittivity of the substrate, μ_r is the relative permeability of the substrate, L_{eff} refers to the equivalent length, and W_{eff} refers to the equivalent width which they are equal to [17]:

$$W_{eff} = W - 1.08.\frac{d^2}{s} + 0.1.\frac{d^2}{W}, \quad (2)$$

$$L_{eff} = L_1 - 1.08.\frac{d^2}{s} + 0.1.\frac{d^2}{L_1} \quad (3)$$

In (2), d refers to the diameter of the vias, s is their longitudinal spacing, W displays the width of the SIW cavity, and L_1 shows the length of the SIW cavity. For HMSIW cavity, the length of the SIW cavity is halved. In this structure, The TM modes cannot guided because of the vias are separated by the dielectric gap [18] which for the better performance of the circuit, d and s are limited as follow [19]:

$$\frac{s}{d} \le 2 \quad (4)$$

In this paper, the center frequency is 5.25 GHz. Table I exhibits the dimensions of the HMSIW PD/PC shown in Fig. 3. In this Table, other dimensions except W, L, s, and d is performed with optimization of proposed structure using EM simulator to get low insertion loss, good return loss in all port and good isolation between output ports. For receive high isolation, part of the Gysel PD is joined to HMSIW cavity. The used Gysel PD is introduced in [20]. In this design, $Z_0=Z_1=Z_3=50$, $Z_2 = \frac{Z_0}{\sqrt{2}}$, and $Z_4 = Z_0\sqrt{2}$ where all the transmission lines are a quarter-wavelength long.

TABLE I

DIMENSIONS OF THE PROPOSED STRUCTURE (UNITS:MM)

W	19.74	L_{t2}	5.42
W_{t1}	1.27	L_{t3}	.8
W_{t2}	1.65	L_{t4}	5.17
W_{t3}	1.42	L_{t5}	2.54
W_{g1}	3.65	L_{g1}	6.35
W_{g2}	2.22	L_{g2}	3.3
L	10.16	s	1.9
L_{t1}	8.5	d	0.95

3-2- EVEN AND ODD MODE ANALYSIS

In the even mode, the microstrip network is open circuit (ponit A) and the scattering parameters in the even mode are the scattering parameters of the HMSIW cavity in the even mode. The current distribution of the HMSIW PD/PC in the even mode shown in Fig. 10.

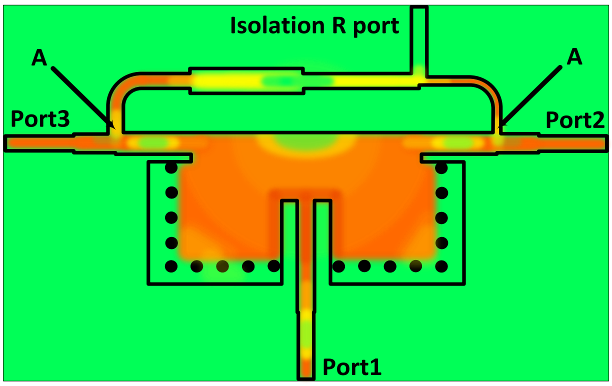

Fig. 10. Current distribution of the HMSIW PD/PC in even mode.

Fig. 11 indicates the current distribution of the HMSIW PD/PC in the odd mode. In this case, the HMSIW cavity is not excited and point A is open circuit. Therefore, the scattering parameters in the odd mode are the scattering parameters of the microstrip network in the odd mode.

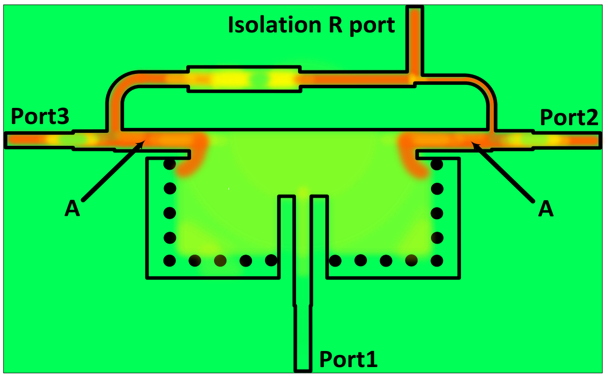

Fig.11. Current distribution of the HMSIW PD/PC in odd mode.

4- SIMULATED AND MEASURED RESULTS

In this paper, the proposed structure is fabricated on a single layer Rogers RO4003C substrate with a thickness of 0.508mm, a relative permittivity of 3.55, and a loss tangent of 0.0027. The photograph of the proposed structure is shown in Fig. 12. The circuit tested by network analyzer (Rohde & Schwarz, zvk). In addition, it is simulated with EM simulator. A good agreement between the simulated and measured results is reported. The measured results show that for a return loss of 15 dB, the bandwidth is from 5.15 to 5.35 GHz (IEEE 802.11a WLAN standard) and over this whole bandwidth, the output return loss and isolation between output ports are better than 14.5 dB and 17.5 dB, respectively. Also, the measured insertion loss is 4.4 ± 0.1 dB and the amplitude imbalance and phase imbalance are less than ±0.26 dB and $\pm3.5^{\circ}$, respectively.

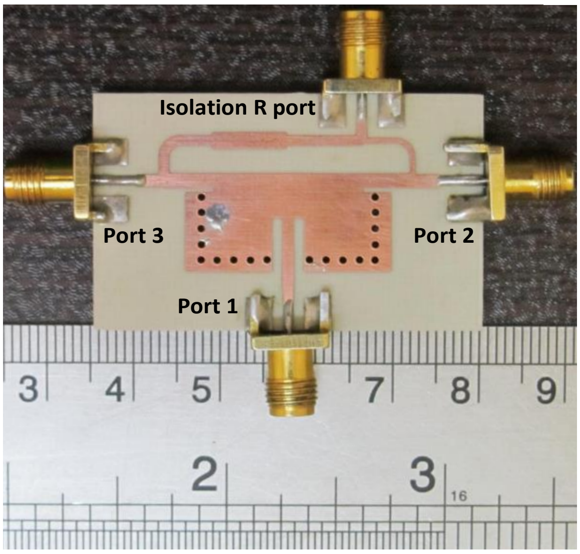

Fig.12. Photograph of the proposed structure.

Fig. 13 illustrates S_{11} and S_{12}, Fig. 14 shows S_{22} and S_{23}, and Fig. 15 and Fig. 16 indicate the simulated and measured results of the amplitude imbalance and phase imbalance, respectively. The slightly difference between the simulated and measured results may be introduced by the tolerances of dielectric constant and the insertion loss of SMA connectors. In the end, these results introduce a circuit with low cost, low loss, high Q-factor, high selectivity, compact size and integration capabilities with planar circuits. Moreover, this design is proper for high power applications.

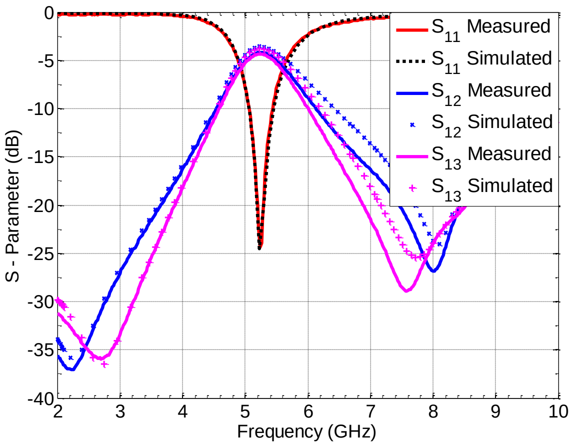

Fig.13. Simulated and measured S_{11}, S_{12}, and S_{13} of the HMSIW PD/PC.

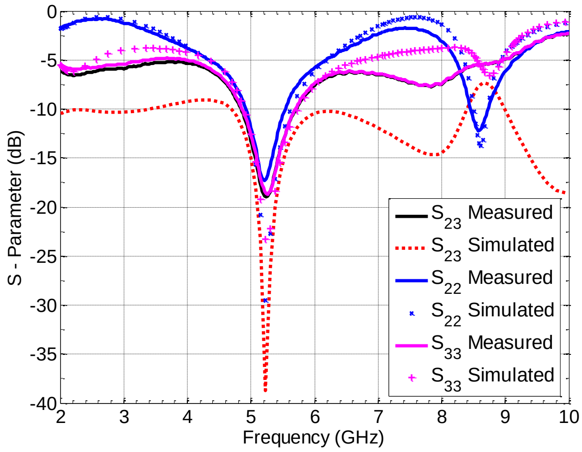

Fig.14. Simulated and measured S_{23}, S_{22}, and S_{33} of the HMSIW PD/PC.

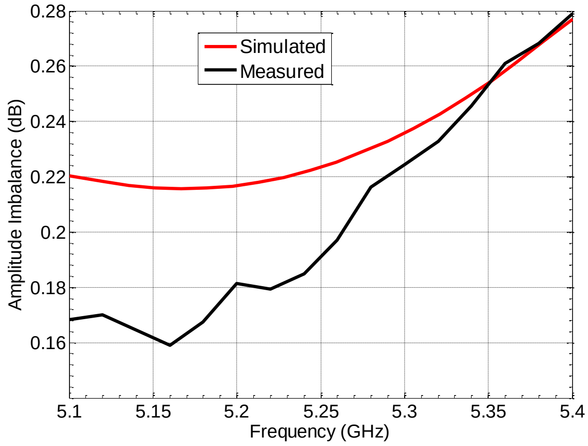

Fig.15. Simulated and measured amplitude imbalance of the HMSIW PD/PC.

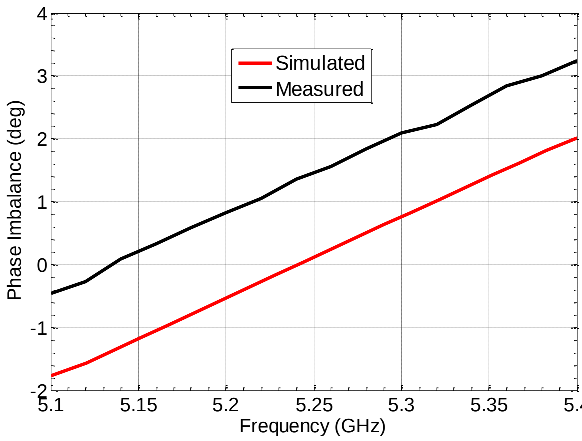

Fig.16. Simulated and measured phase imbalance of the HMSIW PD/PC.

In Table II, a comparison between this work and the other previously works is summarized.

TABLE II

COMPARISON WITH OTHER PREVIOUSLY WORKS

Reference	Size (λ_g^2)	15 dB Return loss FBW (%)	IL (dB)	Isolation
[21]	0.88×4.08	12	<1	No
[22]	1.72×2.57	1.6	<2	Yes
This work	0.61×1.14	3.8	<1.5	Yes

5- CONCLUSION

In this paper, a filtering PD/PC with high isolation for high power applications based on HMSIW has been designed. It can be utilized in microwave and millimeter-wave systems. Also, this circuit has a compact size of $34.57\times18.55\ mm^2$. This model has the excellences of integrate with planar circuits and small size than traditional waveguide PDs and it has the benefit of use for high power applications than SIW/HMSIW Wilkinson PDs.

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