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SUBSTRATE INTEGRATED WAVEGUIDE WILKINSON POWER DIVIDER WITH IMPROVED ISOLATION PERFORMANCE

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Abstract—This work proposes a substrate integrated waveguide (SIW) power divider employing the Wilkinson configuration for improving the isolation performance of conventional T-junction SIW power dividers. Measurement results at 15 GHz show that the isolation (S_{23}, S_{32}) between output ports is about 17 dB and the output return losses (S_{22}, S_{33}) are about 14.5 dB, respectively. The Wilkinson-type performance has been greatly improved from those (7.0 dB $\sim$ 8.0 dB) of conventional T-junction SIW power dividers. The measured input return loss (23 dB) and average insertion loss (3.9 dB) are also improved from those of conventional ones. The proposed Wilkinson SIW divider will play an important role in high performance SIW circuits involving power divisions.

1. INTRODUCTION

Rectangular waveguides, one of the earliest types of microwave transmission lines, are still utilized for many high power and high performance applications. A variety of passive components, such as isolators, detectors, attenuators, and couplers, are available for various standard waveguide bands from 1 GHz up to 220 GHz. However, those components are generally massive and require high precision machining processes leading to different difficulties for mass production at millimeter-wave circuits. Recently, the substrate integrated waveguide (SIW) has been proposed, based on two parallel rows of via holes in a parallel plate waveguide loaded with dielectric [1]. This has many advantages over the rectangular waveguides by its low cost, low profile,

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and compactness in size in addition to the easy integration with planar circuits. The SIW technology has shown a great potential for a wide range of applications such as planar filters, couplers, antennas, and power dividers [1–4].

By the way, power dividers/combiners are one of the key passive components to construct microwave circuits and subsystems. Output matching and isolation of the power dividers are of great importance for achieving the high performance multi-way systems such as antenna array systems by minimizing the mutual coupling between the array elements.

Several SIW power dividers [3, 4] have been proposed using a T-Junction configuration shown in Figure 1(a). Since a 3-port lossless reciprocal network cannot be matched at all ports, they certainly have shown poor isolation and return performance. A Wilkinson-type power divider involving both of half-mode SIW (HM-SIW) and microstrip lines [5] has shown an improved isolation performance. However, the combined structure is not appropriate for entire-SIW circuits and also has higher power loss by the microstrip line section engaged for the bridge resistance connection.

We firstly propose an entire-SIW power divider employing a Wilkinson-type configuration for high performance SIW power distribution circuits. The entire-SIW power divider shows the high performance of very low insertion loss (3.9 dB), small return loss (14.5 dB), and high isolation (17 dB) at 15 GHz. The proposed Wilkinson SIW divider will play an important role for high performance entire-SIW circuits involving multi-way power division and combination.

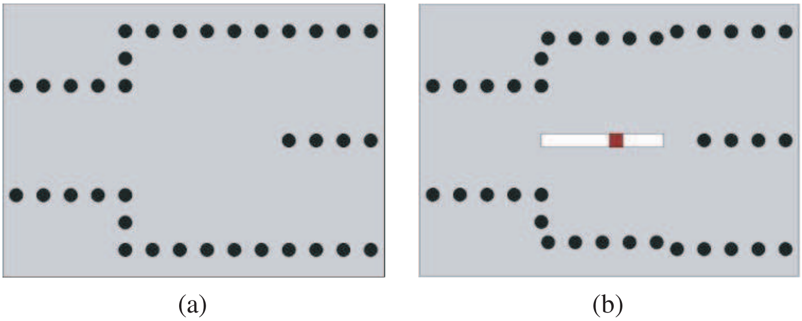

(a) (b)

Figure 1. Top-view of the SIW power dividers; (a) conventional T-junction SIW power divider, (b) proposed Wilkinson SIW power divider.

2. CONFIGURATION AND DESIGN

Since the SIW is a quasi-rectangular waveguide formed by periodic via-hole connections between two metal planes, only TE_{m0} modes can exist and the dominant mode is the TE_{10} mode [7]. Therefore, the SIW modal characteristics are similar to those of the rectangular waveguide mode.

Figure 2 shows the well-known equivalent circuit of the Wilkinson power divider composed of two quarter-wave branch sections and a bridge resistance (R). At the output port-3, the trespassing signal (Pa) through the isolation resistance R effectively cancels the transmitting signal (Pb) through the T-junction since two signals are in out-of-phase by the half-wave propagation delay in two branch line sections. Therefore, the return and isolation characteristics at the output ports are simultaneously improved by the out-of-phase interference. The whole equivalent circuit in Figure 2 has been implemented by an entire-SIW circuit having two HMSIW [8] sections bridged by an isolation resistor as shown in Figure 3. The tapered microstrips are used only for the coaxial connections for the 3-port measurements.

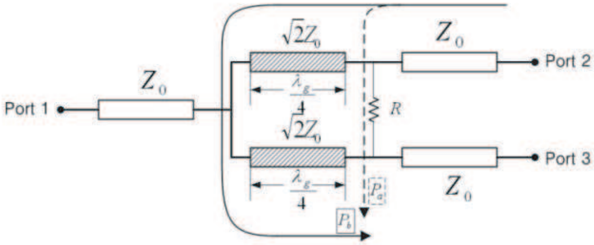


Figure 2. Equivalent circuit of the proposed power divider.

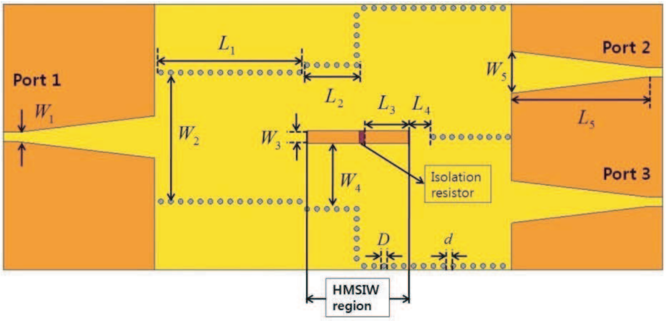
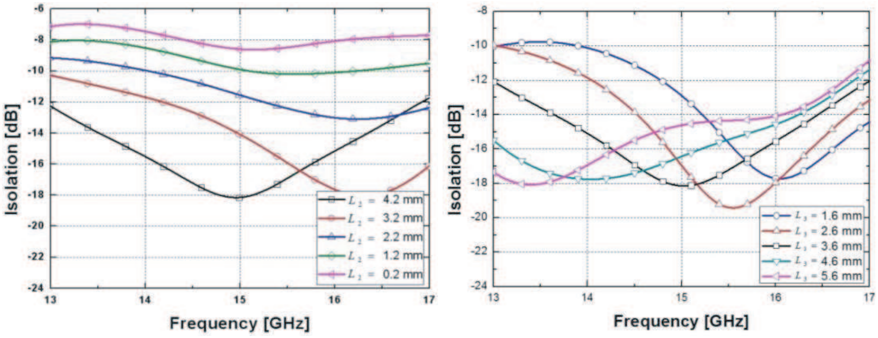


Figure 3. Geometry of the proposed power divider.

Table 1. Parameters of structure.

W_1	W_2	W_3	W_4	W_5	D
0.76 mm	10 mm	1 mm	5.1 mm	3.4 mm	0.4 mm
L_1	L_2	L_3	L_4	L_5	d
11.6 mm	4.2 mm	3.6 mm	1.8 mm	11 mm	0.4 mm



(a) (b)

Figure 4. The isolation effects of the slot length. (a) L_2 variation. (b) L_3 variation.

Many design parameters in Table 1 are involved for the optimum design in considerations of the lateral mode and the discontinuity effects of the SIW circuits. $15\,\Omega$ characteristic impedance (Z_0) and 15 GHz center frequency are chosen for considering the waveguide loss of a Taconic substrate (TLP-3, $\varepsilon_r = 2.33$, thickness $= 0.254$ mm) and the Ku-band applications, respectively. W_2 has been calculated using the well-known waveguide Z_0 equation [8]. W_1, and W_5 are designed for the $50\,\Omega$ coaxial connections linearly tapered from the SIW ports. A $30\,\Omega$ chip resistor is used for the isolation resistor ($R = 2Z_0$) [9]. The HMSIW width (W_4) is about one half of the waveguide width (W_2) [10]. The separation (W_3) between the HMSIW is designed by 4 times the substrate thickness for negligible coupling between the branch sections [11]. L_1 is chosen enough for the mode conversion from the microstrip to the SIW.

The islolation performance is strongly dependent on the slot lengths (L_2, L_3) by the out-of-phase interference between the trespassing signal (Pa) and the transmitting signal (Pb). Figure 4 shows the calculated isolation for different L_2 and L_3. L_2 (4.2 mm) is slightly shorter than the quarter wavelength by the discontinuity effects at both ends of the branch section. L_3 (3.6 mm) is chosen for better isolation by supporting the odd-mode current flowing on the isolation resistor. The small clearance (L_4) from the via wall allows the even mode propagation to the output SIW.

3. SIMULATED AND MEASURED RESULTS

The SIW power divider shown in Figure 5 has been fabricated using a Taconic substrate having $\varepsilon_r = 2.33$ and the thickness $= 0.254$ mm for $15\,\Omega$ characteristic impedance. An isolation resistor ($R = 30\,\Omega$) has been soldered within the slot and the $15\,\Omega$ SIW have been tapered to the $50\,\Omega$ coaxial connections. Figure 6 illustrates the measured and the simulated S-parameters. The measurements are executed using a four port vector network analyzer (HP N5230A VNA) and compared with a 3-D FEM simulator (HFSS v.11) results. Both measured and simulated results show that the proposed Wilkinson SIW power divider has better isolation and better output matching than conventional SIW power dividers.

The measured insertion loss (S_{21}, S_{31}) and input return loss (S_{11}) are within 4.0 ± 0.5 dB and less than 15 dB from 14.48 GHz to 15.75 GHz. The output return loss and the isolation between the output ports are also less than 10 dB from 13.89 GHz to 15.48 GHz. The 15 dB-return-loss bandwidth is approximately 1.27 GHz (fractional bandwidth of 8.47%). By the SMA connector loss, the measured insertion loss is slightly larger than the simulated one. The measured phase difference between $\angle S_{21}$ and $\angle S_{31}$ is also lower than 3.3° over the frequency range from 14 to 16 GHz as shown in Figure 7.

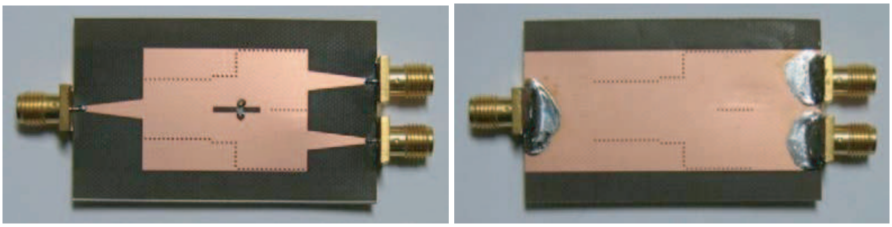
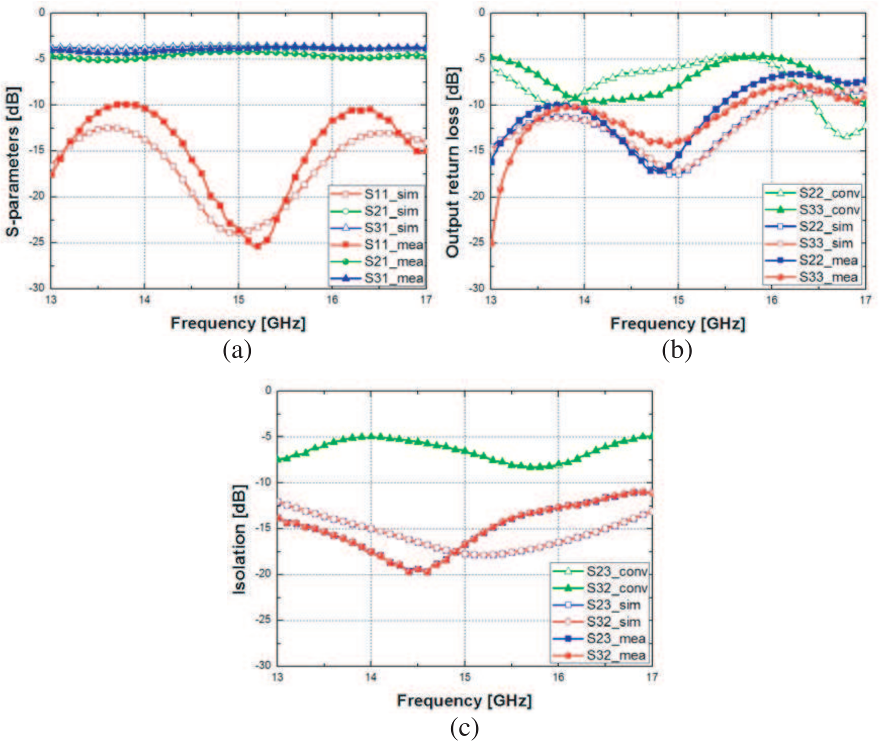

(a) (b)

Figure 5. The fabricated SIW power divider. (a) Top view. (b) Bottom view.



(a) (b)

(c)

Figure 6. The simulated and measured *S*-parameters of the SIW power dividers: (a) the input return loss and the insertion loss, (b) the output return loss, and (c) the output isolation.

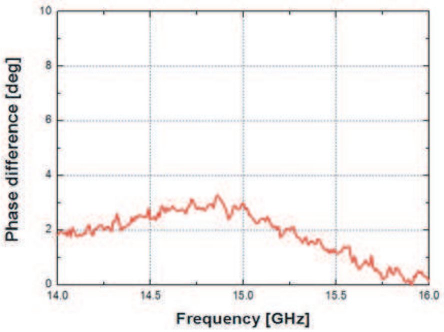


Figure 7. Measured phase difference between the output ports.

4. CONCLUSIONS

A novel SIW power divider, having a true Wilkinson configuration, has been proposed for simultaneous achievement of output ports matching and their isolation. Measurement results at 15 GHz show that the output return losses (S_{22}, S_{33}) are about 14.5 dB and the isolation (S_{23}, S_{32}) between output ports is about 17 dB, respectively. The Wilkinson-type performance has been greatly improved from those (7.0 dB $\sim$ 8.0 dB) of conventional T-junction SIW power dividers. Also improved are the measured average insertion loss (3.9 dB) and input return loss (23 dB). We expect the proposed Wilkinson SIW divider play an important role for high performance SIW circuits involving power dividing and combining.

ACKNOWLEDGMENT

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