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A New Multi-Functional Half Mode Substrate Integrated Waveguide Six-Port Microwave Component

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Abstract—By attention to price of microwave components and need to use of them in many applications, the creation of an integrated component which can incorporate the performances of several components in one structure is a necessity. Therefore, in this paper a novel symmetric six-ports multi-functional microwave component is designed and realized. The proposed component consists of two modified half mode substrates integrated waveguide couplers which are joined and a slot which is attained from joined two mentioned couplers. Despite the slot prevents the exciting of higher order modes in proposed component, it divides signal in two parts by exciting middle SIW ports. By exciting each of the ports as input, the component can act as an equal and an unequal 90-degree couplers or power dividers. The proposed component with mentioned conditions covers 23.5% frequency bandwidth with maximum magnitude and phase error of ± 0.7 dB and ± 0.63 degree, respectively.

1. INTRODUCTION

The rectangular waveguide due to high value of Q-factor and low loss, as an effective transmission line, has already been widely utilized in the microwave and millimetre wave components for many years. Recently, some new planar waveguide structures called substrate integrated waveguides (SIW) have been introduced [1–3]. The field distribution in a SIW is similar to conventional rectangular waveguide. However, it offers some important advantages such as low cost and low profile. Despite that SIW has higher Q-factor than microstrip-line structures, it can be easily integrated with microwave, millimetre wave, and active components. For low microwave bands, the sizes of the SIW blocks may be too large for practical circuits which may affect the integration. Therefore, a new guided wave structure called "half mode substrate integrated waveguide (HMSIW)" is proposed in this study [4]. Hitherto, many microwave and millimetre wave components such as filter, antenna, equal and unequal couplers, and power divider using HMSIW line, have been reported. Unequal power divider and coupler act as effective components in radar and airborne application with directivity pattern and low side-lobe level in order to escape jamming [5]. One of the most important issues in microwave components is no flexibility of them, and this problem results in increased number of microwave components. With attention to price of microwave components and need to use of them in many applications, the creation of an integrated component which can incorporate the performances of several components in one structure is a necessity. To address this problem, the paper presents an HMSIW with a six-port component which consists of two modified HMSIW couplers and a slot. The slot acts as a power divider and also a phase shifting structure which prevents the exciting of higher order modes. The proposed component by selecting each of input and output ports has flexibility to select a state such as: an unequal and an equal 90-degree couplers or a power divider. The proposed component covers a broadband range of frequency which is capable to be employed in an array feed network. Designing details and obtained results of the proposed component are discussed in the following sections.

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2. ARCHITECTURE OF COMPONENT

Figure 1 shows structure of the proposed component which is printed on a layer of Rogers 4003 substrate with relative permittivity of (ε_r =)3.55, loss tangent of ($\tan\delta$ =)0.0027, and substrate thickness of (h = 20 mil) 0.508 mm. It is composed of two HMSIW couplers placed side by side. Details about the proposed HMSIW couplers are referred to in [6]. However, the coupling region of the proposed HMSIW coupler is modified, and it is thinner than that in [6] to attain low values of S_{11} and S_{14}. The thinner region leads to an increase in -3 dB bandwidth. Narrowing down the coupling area prevents higher modes excitation. In order to attain a 50 Ω input impedance, a microstrip feed line with width of W_f = 1.1 mm is used. On account of impedance matching between microstrip and HMSIW feed line (microstrip-to-HMSIW transition), a semi grounded coplanar waveguide is located at the end of microstrip feed line. The total dimension of the component is 41×61 mm^2. Other values of component parameters are: $W_{SIW} = 15$, $W_s = 0.5$, $W_c = 25.5$, $L_c = 14$, $L_s = 16$, $L_{s1} = 13$, $L_f = 8$, $s = 1$, $d = 1.5$ (all values are in mm).

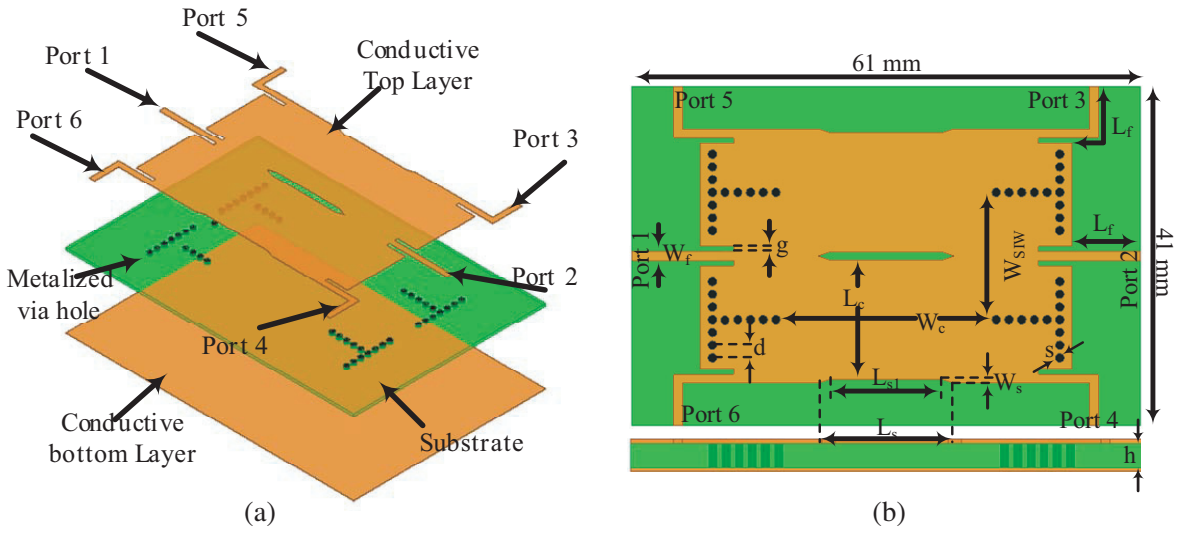


Figure 1. Structure of the proposed six port microwave component. (a) perspective view and (b) top view.

3. RESULT AND DISCUSSION

3.1. HMSIW Transient

The proposed component is simulated and optimized by using High Frequency Structure Simulator (HFSS) ver. 13. One of the most important sections in designing HMSIW structure is implementation transient between microstrip line and HMSIW structure. In this structure, a novel method is used to perform the transient. As displayed in Fig. 2, in order to achieve impedance matching between microstrip feed line and HMSIW structure, a matching slot which plays the role of a load regulator is used. Parametric study of the changing slot dimension is displayed in Fig. 3. By increasing slot length L_t from 3 mm to 4 mm, impedance matching is improved, and the best matching occurs at 4 mm. The impedance matching disturbs, with increasing the slot length from 4 mm to 5 mm. As seen in Fig. 4. The reasons is that by increasing L_t from 3 mm to 4 mm, inductance effect of structure increases, and the best impedance matching is attained at 4 mm. When L_t increases from 4 mm to 5 mm, capacitance effect decreases, and inductance effect improves. Consequently, it leads to getting out of impedance matching at L_t values of more than 4 mm. The proposed transient is capable to cover frequency region between 8 and 14 GHz with about -0.2 dB for S_{12} parameter.

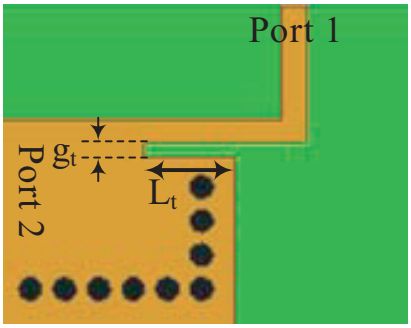


Figure 2. Configuration of transient between HMSIW and microstrip feed line.

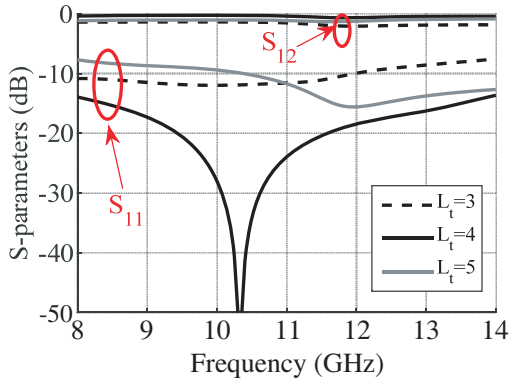


Figure 3. Parametric study of scattering parameters of transient.

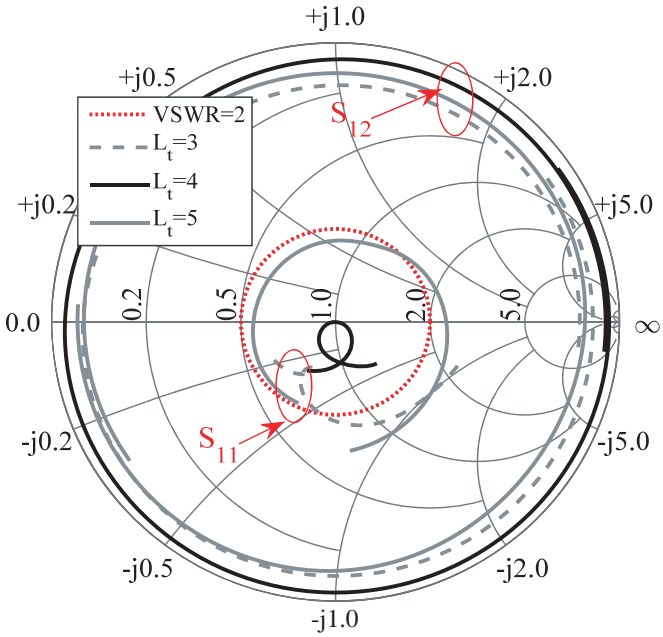


Figure 4. Parametric study of impedance matching curve by changing L_t.

3.2. HMSIW 90-Degree Coupler

Configuration of the proposed HMSIW coupler is presented in Fig. 5. The structure of the coupler is derived from [6]. However, the proposed coupler has an advantage over [6], and it is the creation of a narrow coupling region to prevent higher order modes. Obtained results for simulated magnitude of 90° HMSIW coupler in two states with and without narrowing coupling region are indicated in Figs. 6(a) and (b), respectively. As aforementioned, by modifying coupling region we make an improvement of −3 dB bandwidth as shown in Fig. 6. Phase shifting of the proposed modified HMSIW coupler is shown in Fig. 6(c). The proposed HMSIW coupler is capable of operating in frequency region between 8.74 GHz and 13.28 GHz with ±0.42 dB error in magnitude and about ±5 degrees in phase. The E-field distribution of the HMSIW 90-degree coupler is displayed in Fig. 7. As proved by this figure, the narrower region prevents higher order mode and reduces to return wave to ports 1 and 4.

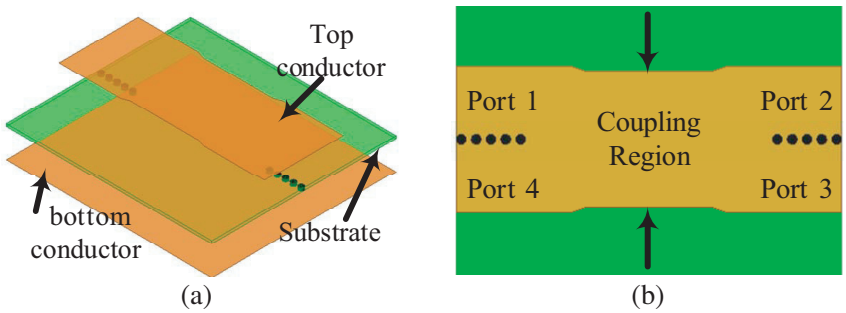


Figure 5. Structure of the proposed HMSIW 90-degree coupler. (a) perspective view and (b) top view.

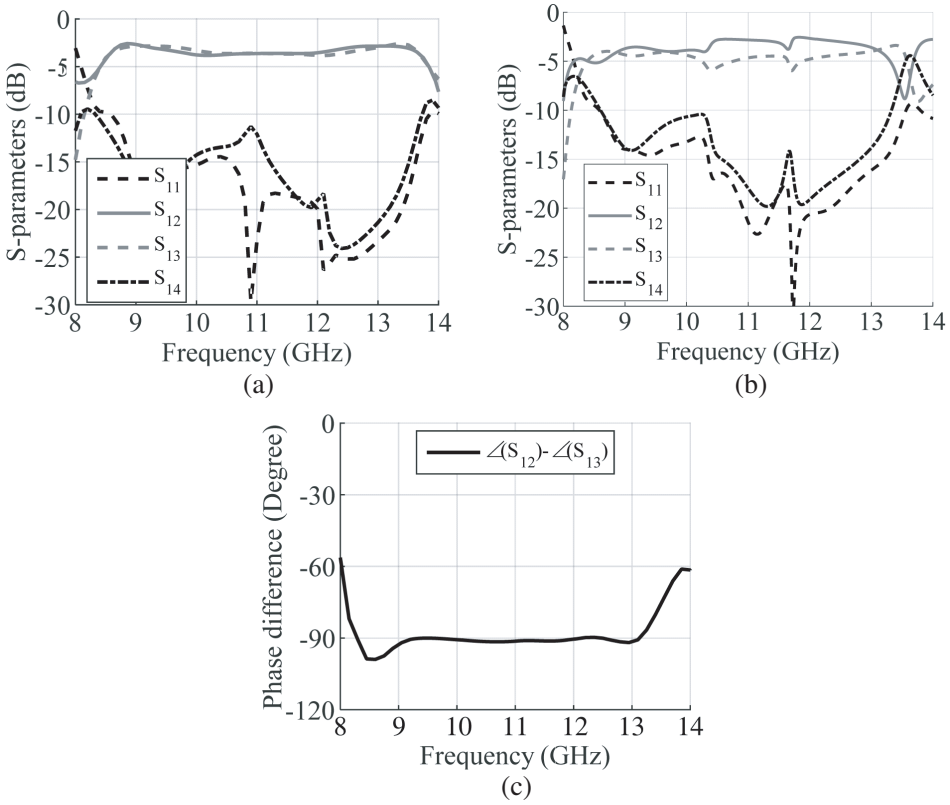


Figure 6. (a) The simulated magnitude of HMSIW coupler with narrowing region; (b) The simulated magnitude of HMSIW coupler without narrowing region; And (c) the phase shifting of HMSIW 90-degree coupler with narrowing region.

3.3. Proposed Multi-Functional 6 Ports Component

As mentioned above, the offered component consists of two HMSIW couplers placed side by side. The principle of operation is based on building an SIW line by combining two HMSIW transmissions. Then, there are two SIW feed lines, which can control the low frequency or cutoff frequency, and four HMSIW feed lines. When port 1 is excited, a signal enters SIW feed line with TE mode after passing the microstrip input feed line and GCPW section that plays the role of a transient between microstrip and SIW feed line, by EH mode. After passing through the SIW line, the signal will reach the slot and is divided to two parts. The divided signals in each of HMSIW coupling regions are separated into two parts. Thus, amplitude results are -3 dB, -6 dB, and -6 dB for output ports 2, 3, and 4, respectively.

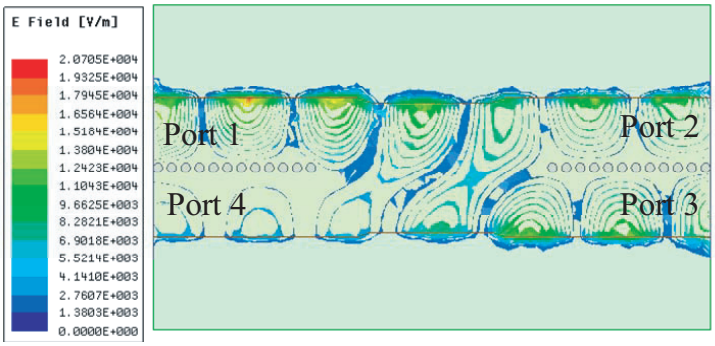


Figure 7. The E-field distribution of HMSIW 90-degree coupler.

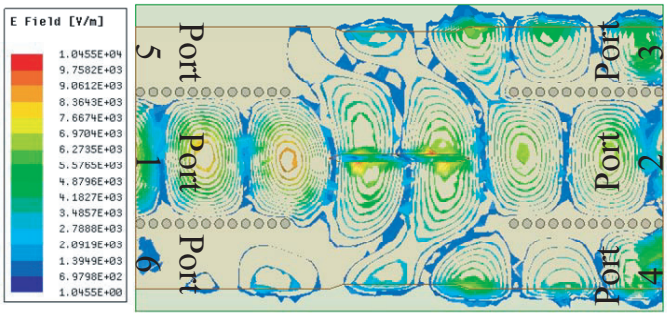


Figure 8. E-field distribution of proposed multi-functional 6-port component.

Meanwhile, phase shifting between ports 2–3 and 2–4 is 90 degrees, and in this condition, ports 5 and 6 are isolated ports. When port 5 of the proposed component is excited, it acts as a −3 dB/90-degree equal divider coupler with output ports 3 (directed port) and 2 (coupled port), and another port is isolated port. As the proposed component is a symmetrical structure, by stimulating each of ports 3, 4, and 6, the results of port 5 will be shown, and results of each of ports 1 and 2, when one of them is input port and other ports are output ports, will be the same. To prove the veracity of what was said, the E-field distribution, when port 1 is input port and other ports are output ports, is shown in Fig. 8. The proposed component is measured by Agilent vector network analyser (VNA) 8722ES. The comparison between simulated and measured magnitude and phase scattering parameters of the suggested component for each of ports 1 and 5 are indicated in Fig. 9 and Fig. 10, respectively. In

Table 1. A Comparison between the functionality of the proposed works with those of some recently reported works; E.P.D is equal power divider, UnE.P.D is unequal power divider, E-Coupler is equal coupler, UnE-Coupler is unequal coupler, and [x] is this work.

Ref.	E.P.D	UnE.P.D	E-Coupler	UnE-Coupler	B.W.	Phase error	Mag. error
[6]	None	None	Ok	None	20%	6°	1 dB
[7]	None	None	Ok	None	16%	6°	2 dB
[8]	None	Non	None	Ok	24%	8°	1 dB
[9]	None	None	Ok	None	15%	----	1 dB
[10]	None	None	None	Ok	18%	∼ 9°	1 dB
[11]	None	None	Ok	None	30%	4°	2 dB
[x]	Ok	None	Ok	Ok	23.5%	0.63°	0.7 dB

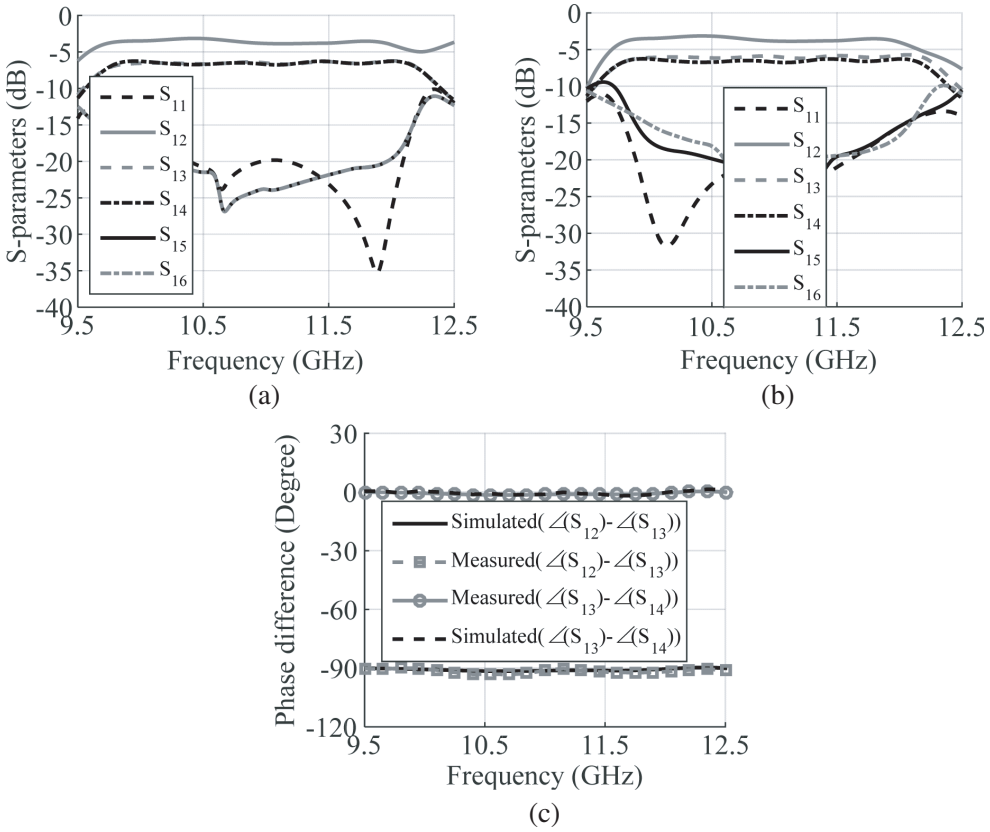
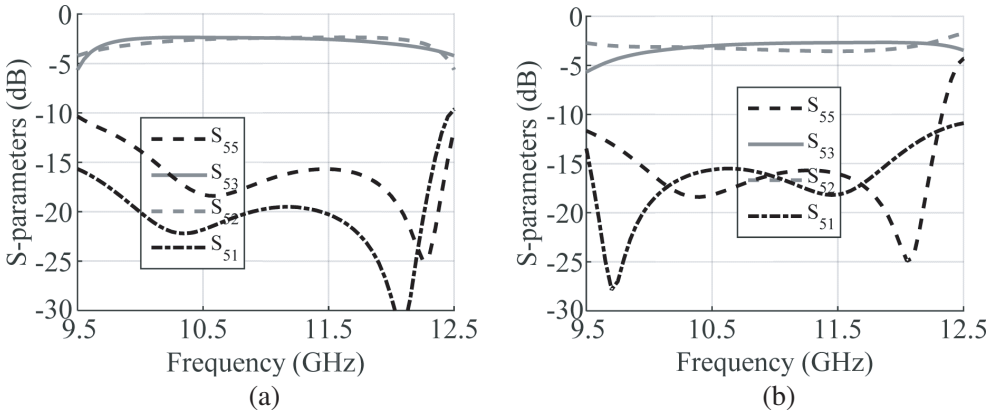


Figure 9. The comparison between simulated and measured magnitudes and phase of S-parameters for input port 1; (a) Simulated magnitude, (b) measured magnitude, and (c) simulated and measured phase difference.

Fig. 9, two unequal (-3 and -6 dB) 90-degree coupler for ports 2–3 and 2–4 and an equal -6 dB power divider for ports 3–4 in frequency range from 9.68 to 12.26 GHz are proved. As seen in Fig. 9, simulated and measured results have good agreement. In Fig. 10, a comparison between simulated and measured results, when port 5 is input port, is illustrated. As indicated by the figure, ports 3 to 6 behave as a 90-degree coupler in frequency range from 10.03 to 12.28 GHz. Therefore, by selecting each of the ports as an input port and other ports as output ports, the structure can behave as a microwave component such as equal and unequal power divider and 90-degree coupler.

Table 1 depicts the performance comparison between the proposed structures and some other



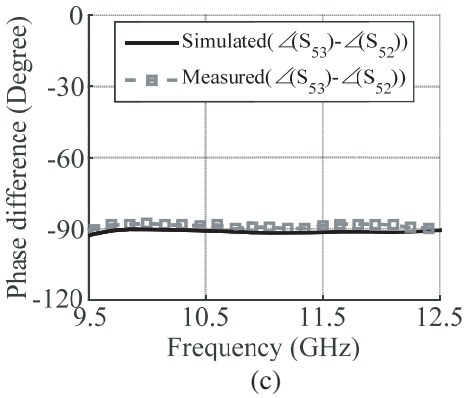


Figure 10. The comparison between simulated and measured magnitudes and phase of S-parameters for input port 5; (a) Simulated magnitude, (b) measured magnitude, and (c) simulated and measured phase difference.

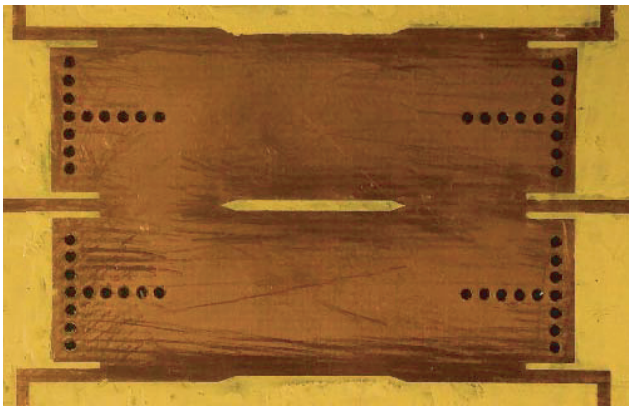


Figure 11. The photograph of a sample of the proposed fabricated structure.

works recently reported in the literature. It is demonstrated that the proposed SIW component is more manoeuvrable and has wider bandwidth than other works reported in recent years. In fact, we can provide an integrated component which, by changing input and output ports, can attain a microwave component such as equal and unequal power divider and coupler in -3 dB and -6 dB states. Compared with some works such as [11], the proposed structure has narrow BW, can play some microwave component roles and has lower phase error than [11].

A photograph of a sample of the proposed fabricated multi-functional six-port microwave component is illustrated in Fig. 11.

4. CONCLUSION

In order to prevent the use of several microwave components in X-band, a novel symmetric six-port multi-functional microwave component has been presented. By selecting each of the ports as the exciting port, the proposed structure can play a role of microwave components. The proposed component with flexibility to change its functional can be used in many practical works, such as array feed network and amplifier. In addition, the proposed component has a good agreement between simulated and measured results for a wide frequency range. The magnitude and phase error of the offered component are also less than 0.7 dB and 0.63 degree, respectively, in all bandwidths. Therefore, the proposed component with flexibility to change among several microwave components by selecting input port and good results in comparison with the recently published components will be considered as future microwave components.

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