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INDUSTRIAL AND ENGINEERING PAPER

Broadband six-way out-of-phase SIW power divider

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A broadband six-way out-of-phase substrate-integrated waveguide (SIW) power divider was designed, analyzed, and fabricated for low loss and out of phase dividing applications. The SIW technology was used to realize the power divider; where it consists of a central dual-disc probe connected with coaxial outer-conductor impedance matching transformer and six SIW-to-microstrip transitions as output probes. Three of the SIW-to-microstrip transitions are located at the top plane, whereas the other three are at the bottom plane of the power divider to achieve the out-of-phase dividing functioning. These transitions are all the same in size and shape for symmetry reason. Good transmissions from coaxial input port to six-way SIW power divider were also achieved. There is a reasonable agreement between measured and simulated results.

Keywords: Power divider, Out of phase, Substrate-integrated waveguide (SIW), Dual-disc probe impedance matching

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I. INTRODUCTION

Power divider has been widely used in many microwave and millimeter-wave systems as a key element in multiplexer, coupler and antenna feeding system. Recently, various power dividers have been presented and developed [1–18]. These designs include: ring-cavity power dividers [1], radial waveguide power dividers [2–6], conical power dividers [7], rectangular waveguide power dividers [8, 9], coaxial waveguide power dividers [10–14], and microstrip line and slotline power divider [15–18]. Conventional rectangular waveguide components have been widely used in low loss and high-power microwave, and millimeter-wave communication systems [1–14]. However, they cannot often satisfy the size and cost requirement of current low-cost highly integrated communication systems. In addition, it is difficult to be integrated with other microwave and millimeter-wave planar circuits (e.g. microstrip, slotline, coplanar waveguide, etc.). In [15–18], microstrip and slotline power divider were presented; good in-band power splitting, impedance matching, isolation, amplitude, and phase balance, and out-of-band rejection are obtained both in simulations and measurements.

In recent years, a new technique, substrate-integrated waveguide (SIW) has been constructed by two parallel rows of via holes in a metalized planar substrate. The SIW is realized by metallic via arrays, which shows the similar propagation characteristics of conventional rectangular waveguide. It has merits of low-cost, low-profile, and easy integration with planar circuits [19].

Several power dividers/combiners based on SIW technology have been investigated and designed [20–27]. Among these SIW power dividers [20–22], they show disadvantage of narrow operation bandwidth due to the resonant nature of their configurations. In [27], a broadband in-phase power divider was demonstrated with the used of voltage probe (dual-disc) to achieve broadband input impedance matching, where 10 dB return loss bandwidth of about 4.4 GHz were achieved. However, the increase in complexity of nowadays millimeter/micrometer-wave systems brings about the need multiple-way out-of-phase passive circuits, which will be of great advantage to enable good connectivity between all interconnects present in the microwave/millimeter-wave systems.

In this paper, an SIW power divider has been presented. This SIW power divider can achieve an arbitrary N-way power-dividing performance in out-of-phase situation. Coaxial dual-disc probe impedance-matching transformer is applied to achieve wider bandwidth performance. A six-way out-of-phase SIW power divider operating at C-band with center frequency of 6.7 GHz is designed and fabricated. The 180° out-of-phase is achieved by changing the polarity of the potential of the output ports (i.e. three of them at the top plane and other three at the bottom plane of the structure). The simulated and measured results show good agreement.

II. DESIGN AND ANALYSIS OF THE SIW POWER DIVIDER

As shown in Fig. 1, a six-way out-of-phase SIW power divider consists of central input coaxial dual-disc probe, six of the SIW-to-microstip transitions; where three of these transitions are situated at the top plane and the other three are at the bottom plane of the structure. The phase difference between

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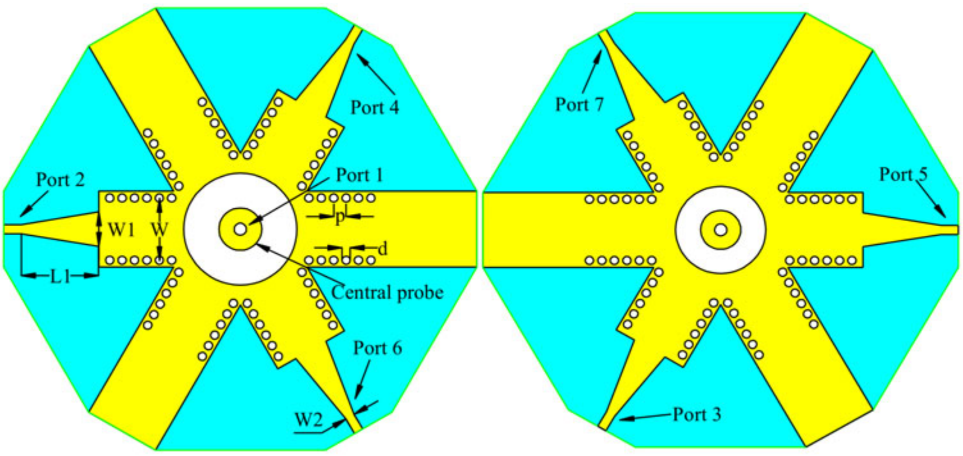


(a) (b)

Fig. 1. Schematic diagram of the SIW power divider: (a) top view, (b) bottom view.

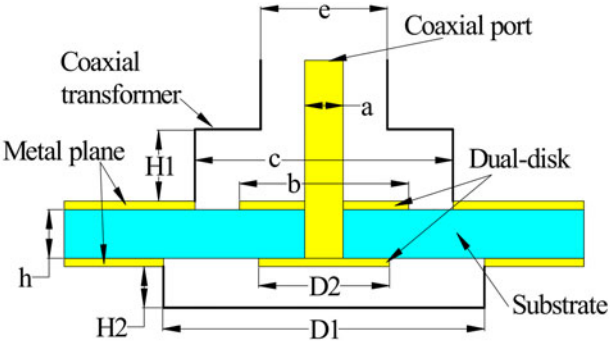


Fig. 2. Schematic illustrations of dual-disc parameters.

two adjacent peripheral ports is 180° out-of-phase thus; the electric field between them is opposite. For symmetry reasons, the six SIW-to-microstrip transitions are identical in shape and size, which can be designed according to [19]. The SIW is a type of dielectric filled substrate with two rows of metallic via to realize electronic walls. With

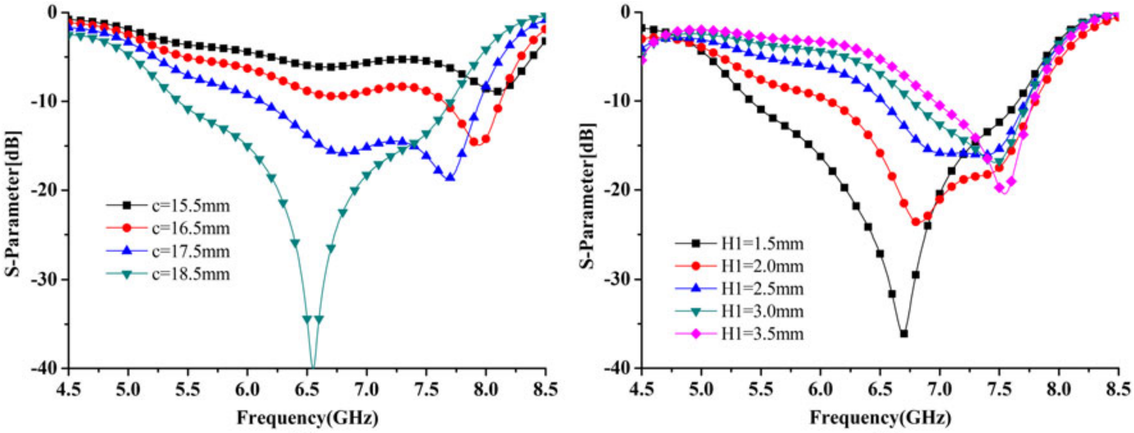
$$p \le 2d, \tag{1.1}$$

$$d \le \lambda_g / 10, \tag{1.2}$$

where λ_g is the guided wavelength. Almost no leakage will exist along the waveguide. Then, the SIW can be modeled by a conventional rectangular waveguide filled with dielectric material.

The out-of-phase SIW power divider is centrally fed using a stepped coaxial line transformer that connects with the central dual-disc probe (Fig. 2). The central dual-disc probe is axially symmetric; which can provide broadband impedance matching from the input coaxial line to the radial line, and can also be processed easily at the substrate. As shown in Fig. 2, the dual-disc probe is as in [27]. So, with a specified coaxial-line input port (e.g. Sub-Miniature-A (SMA) connector), the input admittance of the dual-disc probe in Fig. 2 can be changed by varying c, b, H1, D1, D2, and H2 to be able to achieve a wider bandwidth of the power divider.

Parallel structural design approach is adopted in this paper based on its nature, to be able to combine six-way out-of-phase microwave signal in one step. Finally, High Frequency Structure Simulator (HFSS) full-wave tools were used to optimize the dimensions of the central dual-disc probe of Fig. 2.



(a) (a)

Fig. 3. Dual-disc parameter sweep frequency response: (a) parameter ‘c’, (b) parameter ‘H1’.

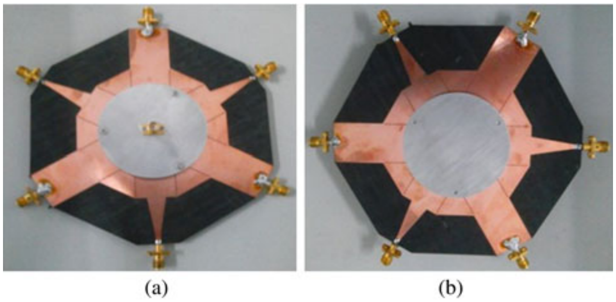


Fig. 4. Photograph of the fabricated power divider: (a) top view, (b) bottom view.

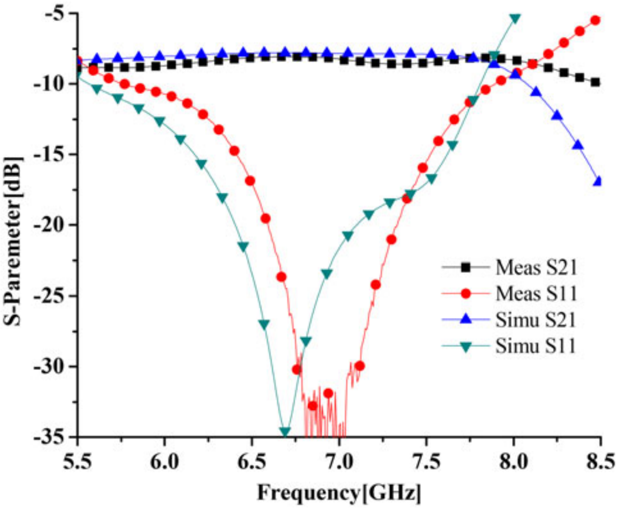


Fig. 5. Measured and simulated S11 and S21 of the SIW power divider.

A) Parametric analysis

Analysis was made on some of the dual-disc probe parameters, to actualize their influence on the performance of the presented power divider structure. Among the parameters, c and H1 parameters were swept and significant effects were observed on the return loss and at the same time the bandwidth of the power divider (see Fig. 3). The sweep was done on the basis of one parameter at a time to recognize independent effect of each parameter on the power divider performances. The values of each parameter are as follows: $W = 21.6$, $d = 0.5$, $p = 0.8$, $W1 = 10$, $L1 = 22.3$, $W2 = 2.7$, $a = 1.2$, $b = 7.2$, $c = 36.4$, $e = 4.2$, $H1 = 1.2$, $H2 = 0.4$, $D1 = 26$, and $D2 = 7.6$ mm.

III. EXPERIMENTAL RESULTS

A six-way out-of-phase SIW power divider has been designed and fabricated on a substrate of thickness 1 mm and relative dielectric constant of 2.65. The presented power divider was simulated and optimized using the commercial software Ansoft HFSS. The final dimensions of the SIW power divider shown in Figs. 1 and 2 are: $W = 21.6$, $d = 0.\ 5$, $p = 0.8$, $W1 = 10$, $L1 = 22.3$, $W2 = 2.7$, $a = 1.2$, $b = 7.2$, $c = 36.4$, $e = 4.2$, $H1 = 1.2$, $H2 = 0.4$, $D1 = 26$, and $D2 = 7.6$ mm. The photograph of the six-way out-of-phase SIW power divider is shown in Fig. 4.

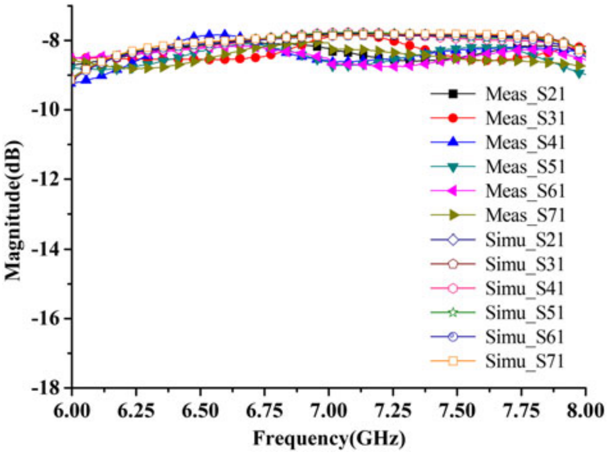


Fig. 6. Measured and simulated transmissions of the SIW power divider.

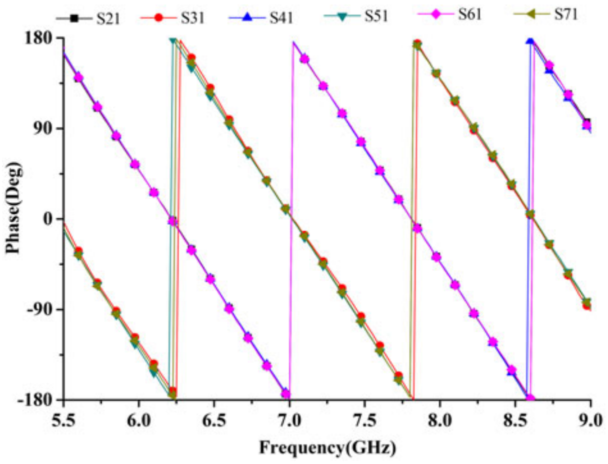


Fig. 7. Measured ports phase angles of the power divider.

Figure 5 shows the simulated and measured results of the six-way out-of-phase SIW power divider. Simulated and measured return losses are both greater than 15 dB at frequency range of (6.17–7.62 GHz) and (6.42–7.53 GHz), respectively.

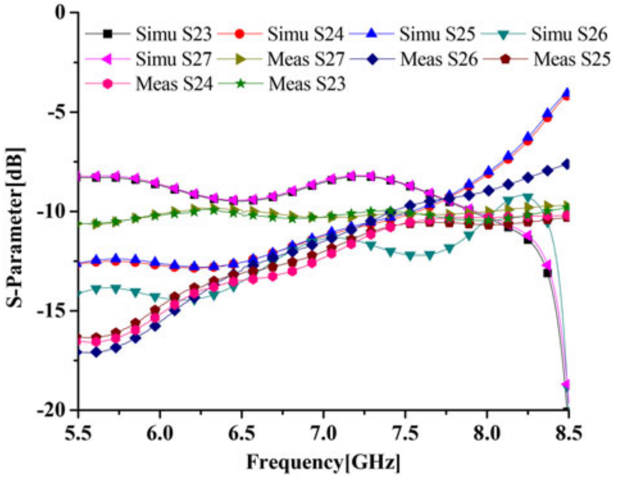


Fig. 8. Simulated and measured isolations of the SIW power divider.

Table 1. A comparison of this works and other works.

Works	In-phase/out-of-phase	Number of ports	Working frequency	Isolation	Insertion loss (dB)
[10]	In-phase	10	11.5–16 GHz (15 dB return loss)	>10 dB	About 0.8
[23]	Out-of-phase	5	3.85–4.2 GHz (10 dB return loss)	Not given	<0.15
[2]	Out-of-phase	9	0.8–1.8 GHz (10 dB return loss)	>5 dB	<1.5
This work	Out-of-phase	7	6.42–7.53 GHz (15 dB return loss)	>8 dB	<0.71

Measured average insertion loss of the proposed six-way out-of-phase SIW power divider is about 8.5 dB in the operational frequency range of (5.5–8.5 GHz). To further extend the operating frequency range, the thickness of the SIW can be increased. Compared to the simulated results, the increased insertion loss is mostly likely related to the dielectric loss of substrate and fabrication errors. The simulated and measured 15 dB bandwidth are both 1.45 GHz and 1.11 GHz from (6.17–7.62 GHz) and from (6.42–7.53 GHz), respectively. However, the measured results agree with the simulated ones reasonably.

Figure 6 depicts the simulated and measured transmissions from central input port to the peripherals output ports, respectively (i.e. Sn1, where $n = 2, 3, 4, 5, 6$, and 7).

From Fig. 7, the measured phase difference between the outputs of fabricated power divider; S21, S41, and S61 are in-phase (i.e. ports 2, 4, and 6 are at top plane), S31, S51, and S71 are also in-phase with one another (i.e. ports 3, 5, and 7 are at the bottom plane), and all the top plane ports are out-of-phase with bottom plane ports. Hence, the 180° out-of-phase function of the designed power divider has been achieved.

Figure 8 displays the simulated and measured isolations of the power divider, where only port 2 isolations (i.e. S23, S24, S35, S26, and S27) were shown on the figure; as remaining ports isolations are of the same pattern with that of the port 2. From the graph, it can be seen that from frequency of 5.5–8 GHz all the isolations are greater than 8.16 and 9.25 dB for simulated and measured results, respectively. A comparison between this work and other works is given (Table 1).

IV. CONCLUSION

A broadband six-way out-of-phase power divider based on SIW technology has been reported. The dual-disc probe was used to achieve broadband impedance matching. The presented power divider was designed, fabricated, and measured. The measured and simulated results show good agreement with each other over the operating frequency range (5.5–8.5 GHz).

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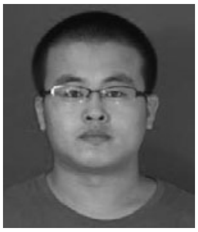

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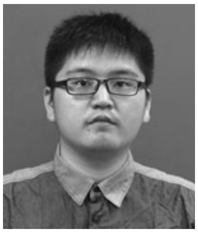

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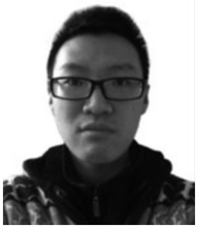

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