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LETTER

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A novel wideband band-pass response power divider with improved out-of-band performances

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Abstract: This paper reports a novel wideband two-way power divider with improved out-of-band rejection based on substrate integrated waveguide (SIW) technology. Periodic radial line slots are etched on the bottom side of SIW to achieve the band-stop characteristic. The band-pass response is achieved by combing the band-stop characteristic of the radial line slots and the high-pass characteristic of SIW. An experimental circuit is fabricated by the traditional printed circuit board technology. The measured results show that the power divider has the advantages of wideband (about 42.8% with center frequency 7 GHz for Return Loss > 10 dB) and sharp roll-off skirts (better than 37 dB/GHz).

Keywords: power divider, wideband, band-pass response, out-of-band performance, substrate integrated waveguide

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

The microwave power dividers are essential passive components of microwave circuits [1]. They are widely applied to divide or combine the power of microwave signals in power amplifiers and antenna arrays. In the past few years, researchers have done much work on power dividers, which are mostly focused on the characteristic such as wideband [2], dual-band [3], small size [4], and high selectivity [5]. The conventional power divider has the disadvantage of poor frequency selectivity. A novel device integrating power divider with band-pass filter is proposed in [6], but it has to design power divider and filter at the same time. In [7], a power divider realized by metal rectangular waveguide shows good out-of-band rejection. However, its characteristic is restricted seriously in the practical project application because of its large size and narrow bandwidth. SIW technology has the advantages of cheap to fabricated and easy to be integrated with other planar circuits. Many researchers have reported power dividers based on SIW technology [8, 9].

To overcome the bandwidth limitation and the poor out-of-band rejection of the power divider, a novel wideband SIW power divider with enhanced selectivity is proposed in this letter. A prototype of the proposed power divider with the centre frequency of 7 GHz has been fabricated and measured. The measured results indicate that the proposed power divider has wide bandwidth (about 42.8% for Return Loss >10 dB) and good selectivity.

2 Analysis and design of the power divider

The whole geometry structure of the proposed power divider is shown in Fig. 1. Four periodic radial line slots are etched on the bottom side of the SIW. As shown in Fig. 1(c), each periodic radial line slot consists of two U-shaped slots, which are symmetrically connected by a small rectangular aperture.

Firstly, the proposed power divider acts on the main mode TE_{10} merely in the working band. For the TE_{10} dominant mode, the cut-off frequency of the SIW can be calculated by the following formula [10]:

$$fc_{(TE_{10})} = \frac{1}{2W_{eff}\sqrt{\mu\epsilon}} \quad (1)$$

where μ and ϵ are the permeability and permittivity of the substrate W_{eff} is the equivalent width of SIW;. W_{eff} is determined by three parameters, W (the width of SIW), g (the distance between two adjacent metallic vias), and d (the diameter of the metallic vias). A good approximation (g and d/W are sufficiently small) to

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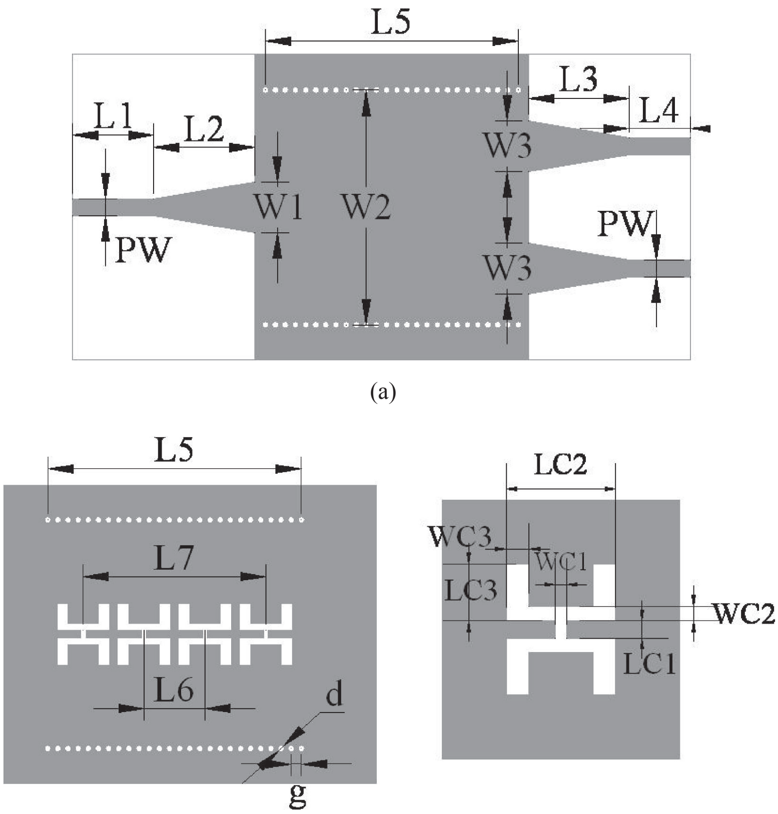

Fig. 1. Configuration of the proposed power divider (a) Top view of the proposed power divider. (b) Bottom view of the proposed power divider. (c) Geometries of the radial line slot

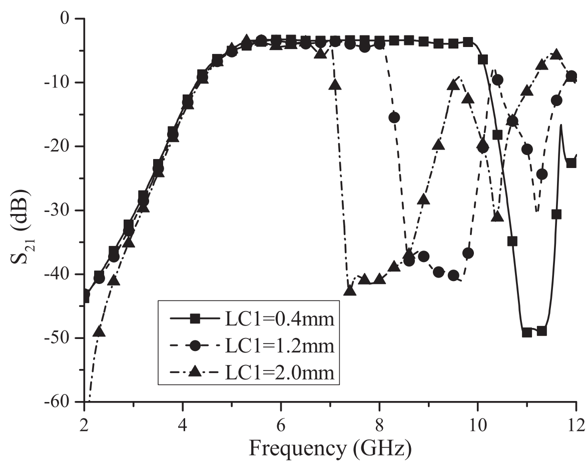

Fig. 2. Simulated frequency responses of the power divider with different LC1 values.

calculate the effective width W_{eff} of a substrate integrated waveguide is given by the following equation [11]. The cut-off frequency of TE_{10} mode in this design is 5 GHz.

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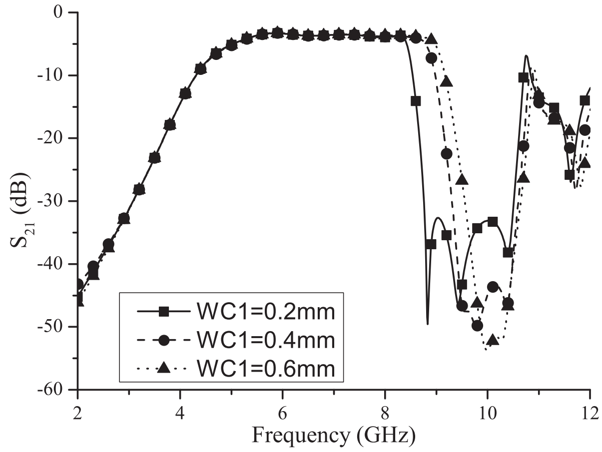

Fig. 3. Simulated frequency responses of the power divider with different WC1 values.

Table I. Dimensions of the proposed power divider (units: mm)

PW	W1	W2	W3	L1	L2	L3	L4	L5	L6
1.58	5	23	5	8	10	10	6	25	6
L7	WC1	WC2	WC3	LC1	LC2	LC3	d	g	
18	0.5	0.7	1.1	0.8	5.2	2.7	0.3	1	

$$W_{eff} = W - 1.08\frac{d}{g} + 0.1\frac{d^2}{W} \tag{2}$$

As known to all, the SIWs have high pass performance and the electromagnetic band gap structures have band-stop characteristics. The periodic radial line slots are etched on the bottom of the SIW to realize the filtering response. Fig. 2 shows we can get different bandwidths of the power divider by changing LC1. Fig. 3 shows the simulated frequency responses of the power divider with different WC1 values. In a word, by changing the dimensions of the slots, different center frequencies and bandwidths of the proposed power divider could be achieved.

In order to connect the SIW power divider to a network analyser to make the measurements, microstrip-to-SIW transitions are designed to connect the SIW and the 50 Ω microstrip. The initial size of the microstrip-to-SIW transition comes from the equation in [12]. The final size and location of the the microstrip-to-SIW transition is obtained on the basis of iterative simulations. The transitions increase the size of the SIW power divider.

3 Experimental results

The prototype power divider is built on a substrate with the thickness of 0.508 mm, the relative dielectric constant of 2.2 and the dielectric loss tangent of 0.0009 (at 10 GHz). The geometrical sizes are summarised in Table I. Fig. 4 shows the fabricated SIW power divider.

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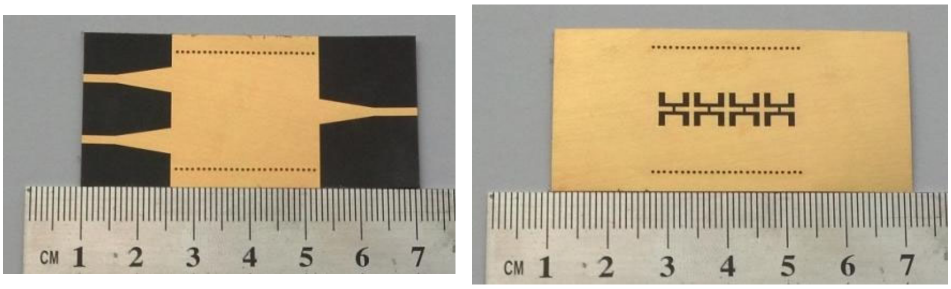

Fig. 4. Photograph of the fabricated power divider: (a) Top view of the proposed power divider. (b) Bottom view of the proposed power divider.

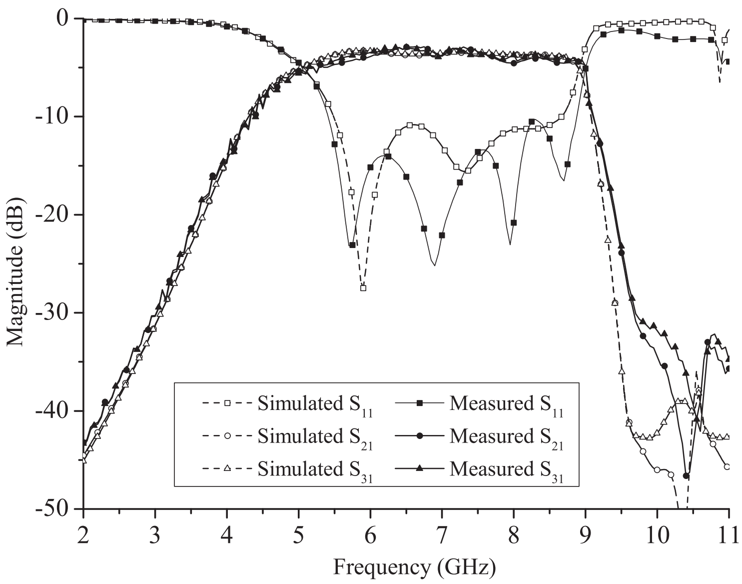

Fig. 5. The simulated and measured results of proposed power divider.

Fig. 5 shows the simulated and measured results of the proposed power divider. It can be seen that the measured results show a good agreement with the simulated ones. The measured insertion losses are within 3.8 ± 0.55 dB in the pass-band, while the simulated insertion losses are in 3.5 ± 0.3 dB. From 5.5 to 8.5 GHz the measured return loss is better than 10 dB. Differences between the simulated and measured insertion loss are caused by the SMA connectors, the microstrip lines and the fabrication errors. At the upper stop-band from 9.6 to 11 GHz the rejection is better than 25 dB. Moreover, the roll-off factor of the proposed power divider in the upper sideband is better than 37 dB/GHz, which means that it has good out-of-band performances. Comparisons between published power dividers and the proposed one are shown in Table II. Obviously, the proposed power divider exhibits a better fractional bandwidth.

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Table II. Performance comparisons between published power dividers and the proposed one

Ref	Fractional bandwidth	Insertion Loss (pass band)	Return Loss (pass band)	Normalised circuit size
[6]	12.5%	3.9 dB	$>$14 dB	1.08×1.8
[7]	5.7%	3.3 dB	$>$20 dB	Not mentioned
[8]	38%	3.7 ± 0.4 dB	$>$13 dB	4.05×7.6
[9]	38%	3.7 ± 0.5 dB	$>$10 dB	4.59×6.45
This work	42.8%	3.8 ± 0.55 dB	$>$10 dB	5.37×5.83

4 Conclusion

In this Letter, a new wideband SIW power divider with good out-of-band rejection is presented. The proposed power divider shows advantages of low cost to fabricate, easy to integrate with other planar circuits and high selectivity with wide fractional bandwidth. The Measured results show good agreement with the simulated ones. It could be a good candidate for wideband wireless communication applications.

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