A Two-Layer Substrate Integrated Waveguide Out-of-Phase Power Divider

Qi Chen and Jun Xu
School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu, China
Email: chenqi0313@gmail.com, xujun@uestc.edu.cn

***Abstract*—Substrate integrated waveguides (SIWs) have been proposed and applied to develop a two-way out-of-phase power divider in this paper. This newly proposed structure shows good performance in wide frequency range from 8.6 GHz to 10.6 GHz. The proposed multilayer SIW out-of phase power divider consists of two layer of substrates of Rogers 5880 with thickness of 0.508 millimeters. The input at the upper layer is coupled to two outputs at the lower layer by a narrow metal slot located in the broad wall of waveguide. The proposed power divider shows low insertion loss in a wide passband and good outputs imbalance. In the frequency range from 8.6 GHz to 10.6 GHz, the insertion losses are between -3.32 dB and -3.66 dB, with return losses less than -10 dB. At the same time, the magnitude differences between two outputs S21 and S31 are within 0.27 dB. The phase differences between two outputs are as low as $180^{\circ} \pm 0.8^{\circ}$.The advantage of this structure is its good performance in wide frequency range from 8.6 GHz to 10.6 GHz. Also, the proposed structure has low profile and is easy and cheap to fabricate. The SIW structure can be integrated easily with other planar circuits such as microstrip circuits .**

***Index Terms*—power divider, substrate integrated waveguide, multilayer**

I. Introduction

Traditional waveguide has advantages of low insertion loss and high-power handling capacities, but its large size and high cost limit its applies especially in cases that allow only small volume and light weight. Recently a new structure, named substrate integrated waveguide (SIW), is constructed by two parallel rows of via holes in a metalized planar substrate as shown in Fig. 1. Due to their low loss, low cost, high power handling capability, and easy integration with other planar circuits, SIWs have attracted much attention in various microwave applications.

SIWs have been proposed and applied to develop many high-quality microwave and millimeter wave components, such as power dividers, filters, waveguide bends and couplers [1]-[7]. An EM-based design of SIW interconnects with microstrip transitions was described in [1]. A 3-D E-plane bends based on the SIW technology are presented in [2]. Design considerations are discussed with respect to H-plane step, post resonator and bend in [3]. A new class of SIW cavity bandpass filters based on the concept of defected ground structures are designed in [4]. In [5], a narrow-wall double-slot 3 dB directional coupler based on SIW is proposed, which keeps the advantages of an SIW coupler but with a reduction of nearly one-half in size and better isolation.

Power divider is a key component in modern communication systems, it can be used in multiplexers, coupler and antenna feeding systems. In [6], a multilayer substrate integrated waveguide four-way out-of phase power divider is designed by using a vertical Y-junction and a lateral Y-junction of half mode substrate integrated waveguides. A Y-junction four-way power divider is proposed by integrating the SIW power divider and the half-mode substrate integrated waveguide (HMSIM) power divider in [7].

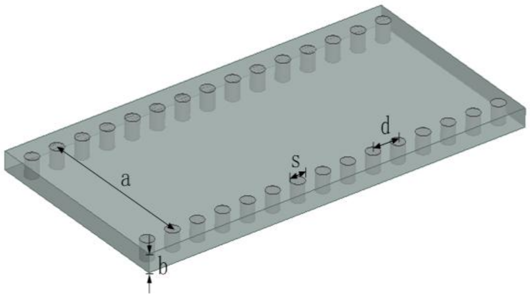

Figure 1. Configuration of a SIW structure

In this paper, a two-layer SIW power divider based on printed circuit board (PCB) is studied and designed. The SIW power dividers split the input power into two outputs through a narrow slot in the broad side of the waveguide. The proposed structure is constructed by two layers of substrate and a coupling metal plane with narrow coupling slot between two substrates. The two outputs are out of phase. The proposed power divider exhibits good passband performance including low insert loss and excellent outputs imbalance. This PCB based power divider also has advantage of easy and cheap to fabricate.

II. Design of the Two Layer Power Divider

The 3-D view of a SIW is shown in Fig. 1. The SIW is made up by two parallel rows of metalized via holes in a metalized planar substrate. This structure may be seen as a rectangular waveguide filled with dielectric. The

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diameter of via holes is *s* and the thickness of substrate is b. The distance between two rows of via holes is *a*, and the distance between two adjacent via holes in same row is *d*. It is obvious that the SIW is period structure with period length of *d*.

Since the SIW is a quasi-rectangular waveguide, the cutoff frequencies of the SIW modes f_{cmn} can be calculated as follow [1], [8]:

$$f_{Cmn} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{(\frac{m\pi}{a_{eqv}})^2 + (\frac{n\pi}{b})^2} \tag{1}$$

where a_{eqv} and b are equivalent width and height of SIW, m and n represent mode order numbers, ε and μ are permeability and permittivity, respectively. The cutoff frequency for dominant mode TE_{10} can be calculated as,

$$f_{C10} = \frac{1}{2a_{eqv}\sqrt{\mu\varepsilon}} \tag{2}$$

For the structure shown in Fig. 1, We can calculate the equivalent width a_{eqv} as follow

$$a_{\text{eqv}} = a - 1.08 \cdot \frac{d^2}{s} + 0.1 \cdot \frac{d^2}{a} \tag{3}$$

Two useful empirical criteria to establish upper bounds for s and d are

$$s \le 2d \tag{4}$$

$$d \le \frac{\lambda_g}{5} \tag{5}$$

where λ_g is the guided wavelength. For the dominant mode TE_{10},

$$\lambda_{g10} = \frac{2\pi}{\sqrt{(\frac{\varepsilon_r \omega^2}{c^2})^2 + (\frac{\pi}{a})^2}} \tag{6}$$

If the first higher-order mode propagating along the SIW is the TE_{m0} mode, from (2) and (4) an upper limit for the via diameter is given by

$$d \le \frac{2a}{5\sqrt{m^2 - 1}} \tag{7}$$

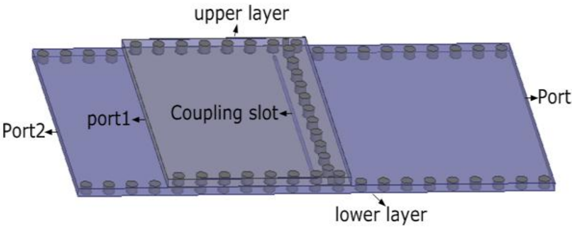

Figure 2. The structure of the proposed SIW power divider

Fig. 2 shows the structure of the proposed two-layer out-of-phase SIW based power divider with narrow coupling slots.

As shown in Fig. 2, the power divider is built on two 0.508 mm-thick substrates of Rogers 5880 with relative permittivity of 2.2 and loss tangent of 0.0009. The coupling metal plane with a narrow coupling slot locates between two substrates. The mode power of the input SIW in the upper substrate is coupled through the narrow slot in the coupling metal layer and divided into two out-of-phase outputs in a lower substrate.

As the SIW structure could not be connect to a network analyzer directly, a microstrip-to-SIW transitions are designed to connected SIW and the 50-ohm microstrip to make the measurements. The designed microstrip-to-SIW transitions is shown in Fig. 3. A triangle tapered line is employed in the designed microstrip-to-SIW transition. Good performance could be achieved by optimization of the angle and length of the triangle tapered line.

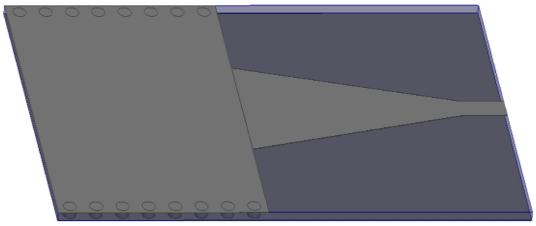

Figure 3. The proposed microstrip-to-SIW transition

The design of the proposed power divider with microstrip-to-SIW transitions is shown in Fig. 4. The width of the 50-ohm microstrip is *W1*. The length and width of the triangle tapered line in the microstrip-to-SIW transition section are *L1* and *W2*. The length and width of the input SIW in the upper substrate and output SIW in the lower substrate are L2 , W3 and L6, W6, respectively. The length and width of the coupling slot locates at the metal plane between two substrates are *L3* and *W4.*

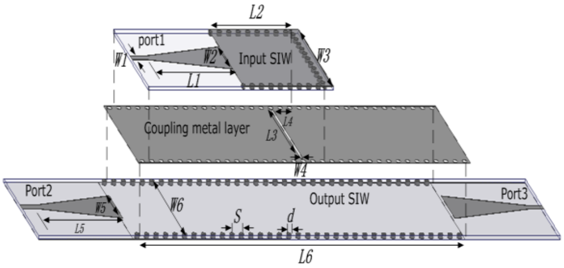

Figure 4. Design of the proposed power divider with microstrip-to-SIW transitions

The width of SIW(*W3, W6*) is designed for working in the frequency of X-band. The dimensions of via holes (s and d), which are designed to reduce leakage from the substrate integrated waveguide structure, can be decided by formulas (4) and (5).

TABLE I. PARAMETERS OF THE PROPOSED POWER DIVIDER (UNIT: MILIMETERS)

Dimensions	values	Dimensions	values
W1	1.58	L2	18.11
W2	8.96	L3	7.94
W3	19.01	L4	4.11
W4	0.052	L5	13.05
W5	8.96	L6	68
W6	19.01	s	2
L1	13.05	d	1

Table I gives the dimensions of the proposed two-way out-phase power divider. The thickness of the coupling metal plane between two substrates is 0.034 millimetres.

III. RESULTS

The top view of the proposed SIW power divider with microstrip-to-SIW transitions is shown in Fig. 5. The input port (port1 in Fig. 5) locates at the upper substrate while the two outputs (port2 and port3) locate at the lower layer substrate. The proposed structure was built with a two-layer substrate with thickness of 0.508 mm, relative dielectric constant of 2.2 and loss tangent of 0.0009. The impedance of input and output microstrip was designed to 50 ohms at a center frequency of 9.5 GHz.

Three microstrip-to-SIW transitions in the proposed structure were designed to connect the microstrip lines and the SIWs. The input power come in from a 50-ohm microstrip and then come through a microstrip-to-SIW transition before arriving at the SIW structure. A narrow slot was employed to divide the input power into two way outputs. The two outputs with 180 degrees phase difference go through the output SIW in the opposite direction. In order to facilitate measurements, microstrip-to-SIW transitions are used to transform the SIW to 50-ohm microstip.

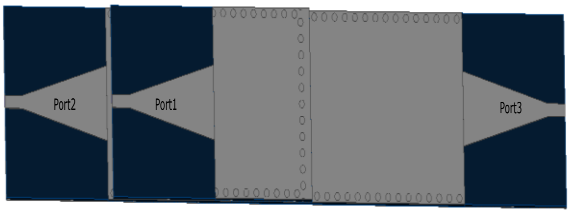

Figure 5. Top view of the proposed SIW power divider with microstrip-to-SIW transitions

The simulations are carried out using Ansoft HFSS package. Fig. 6 shows the optimized results of the SIW power divider As shown in Fig. 6, in a wide frequency range from 8.6 GHz to 10.6 GHz, the return losses are less than -10 dB, and the insertion losses are between -3.32 dB and -3.66 dB. The magnitude differences between two outputs S21 and S31 are within 0.27 dB in the frequency range from 8.6 to 10.6 GHz.

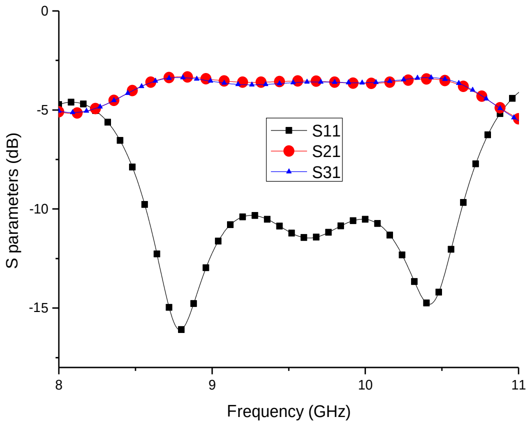

Figure 6. The optimized result of the SIW power divider

Fig. 7 shows the phase differences between $\angle S21$ and $\angle S31$. We can see from the figure that the phase differences between two output are relatively low. Over a wide frequency range from 8 to11 GHz, the phase differences between two outputs are as low as $180^{\circ} \pm 0.8^{\circ}$.

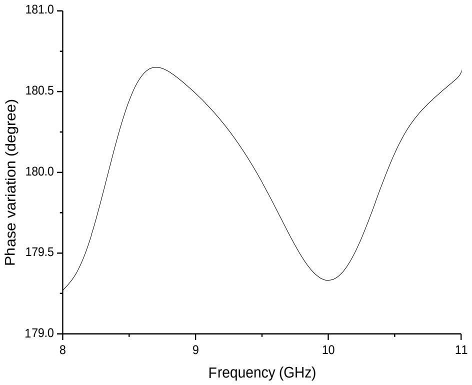

Figure 7. Phase difference between the output ports

IV. CONCLUSION

This paper presents and demonstrates a two-way out-phase power divider based on two-layer substrate-integrated waveguides. In the proposed structure, an input SIW in a upper layer is divided into two output SIWs in a lower layer by coupling the energy from a narrow slot etched on the broad side of the SIW.

The proposed power divider shows good performance in a wide range of frequency. Simulated results show that the out-of-phase power divider exhibits low passband insertion loss in a broad bandwidth. The outputs imbalance is also very good. The proposed structure has advantages of cheap to fabricate, compact in size and easy to integrate with planar circuits. The proposed out-of-phase power divider can be served as a building block in millimeter-wave systems.

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Qi Chen was born in Hunan province, China, in 1984. He received the B.S. and M.S. degree in radio physics from University of Electronic Science and Technology of China, Chengdu, China, in 2006 and 2009 respectively. He is currently working towards the Ph.D. degree in radio physics, University of Electronic Science and Technology of China, Chengdu, China. His current research interests include advanced microwave and millimeter-wave devices and circuits, substrate integrated waveguide (SIW) passive components, passive circuits working at frequencies up to 300 GHz.

Jun Xu was born in Chengdu, China, in March 1963. He received the Graduate degree from the Department of Electromagnetic Engineering, Chengdu Institute of Radio Engineering, Chengdu, in July 1984. He received the Masters degree in July 1990. In July 2002, he was granted the Post Ph.D., electronics physics major. Currently, he is Dean of Academic Affairs, School of Physical Electronics University of Electronic Science and Technology of China. He joined the University of Electronic Science and Technology of China, Chengdu, in 1984. In June 1998, he was selected as the Project Person of Ability for the second term at the university. In June 2000, he was promoted to Professor. His current research interests include electromagnetic theory and microwave technology, millimeter wave hybrid integrated technology, millimeter wave communication, and radar radio frequency technology.