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Design of Ku-band power divider using Substrate Integrated Waveguide technique

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ABSTRACT

A Ku-band Substrate Integrated Waveguide power divider is proposed. In this work, the SIW power divider is designed with T-junction configuration. The SIW technique enables the power divider to have low insertion loss, low cost and features uniplanar circuit. An additional of metallic via hole is added in the center of the junction to improve the return loss performance of the T-junction SIW power divider. The simulated input return losses at port 1 are better than 27 dB, and features equal power division of about -3.1 dB ±0.4 dB at both output ports across frequency range of 13.5-18 GHz. The SIW power divider is fabricated, and the measurement results show acceptable performances. Since there are some losses contributed by the SMA connector of the fabricated SIW power divider prototype, an additional SIW transmission line is simulated and fabricated to analyze the connector loss.

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1. INTRODUCTION

In microwave systems, one of the crucial components used to divide signal power is power divider. This component is mostly used in the transmission line for the communication and antenna system which needs around the laboratory for the help of developing, maintenance, configuration, calibration, and for the help of designing new microwave equipment or devices. The power divider is one of the passive electronic devices. This type of power divider is used in many microwave application, such as the distribution of low power signal for two or multiple antennas and intermodulation distortion measurement where the power divider is used to combine two power signal and produce one signal outputs [1].

From the microwave research trend, the substrate integration innovation of SIW is an appropriate design for the improvement of microwaves signal propagation. SIW is the simplest method to use in microwave component because of the immaterial radiation losses, particularly for wide frequency applications, and give the likelihood to be fabricated in planar innovations. An SIW design is similar to the standard rectangular waveguide. It is worked by applying a dielectric substrate inside two metal layers, then transmitting the signal in the form of the electromagnetic field with the arrangement of two columns of metalised vias on both sides. Also, the rising methods coordinate the propagation of microwave in the active and passive devices such as the power divider [2]. The SIW technique also has been used in the design of coupler [3], antenna [4] and filter [5].

A few SIW power dividers designs were demonstrated in the past few years [6-12]. Those designing methods have been proposed to develop the SIW power divider with different materials and different operating band. The SIW power divider with T-Junction configuration is done on Ku-Band [6], Ka-band [7] and 10-15 GHz frequency band [8]. Others configuration such as Half-mode SIW [9, 10] and DGS technology [11] is also proposed. There is also an SIW power divider for Antenna Feed systems [12]. The T-junction configuration SIW power divider has been used in the design of the SIW six-port [13].

An SIW power divider working on Ku-Band is presented in this paper. As compared to the previously published works on SIW power divider, this SIW power divider is easier to design with the T-junction configuration and can further optimize the insertion loss performance with the additional via hole. The presented SIW power divider is using a T-junction configuration and has a low insertion loss and can function as a power splitter.

2. CONFIGURATION AND DESIGN

The structure of the SIW power divider is formed by T-junction configuration. The design layout had been presented in Figure 1. As depicted in Figure 1, the parameters W_{eq} and W_{tp} represent the equivalent width of the SIW structure and the tapper width respectively. The parameter d represents the diameter of the via while the separation of via is represented by parameter p. X_p is the length to be optimised to achieve the required operating frequency of the SIW power divider.

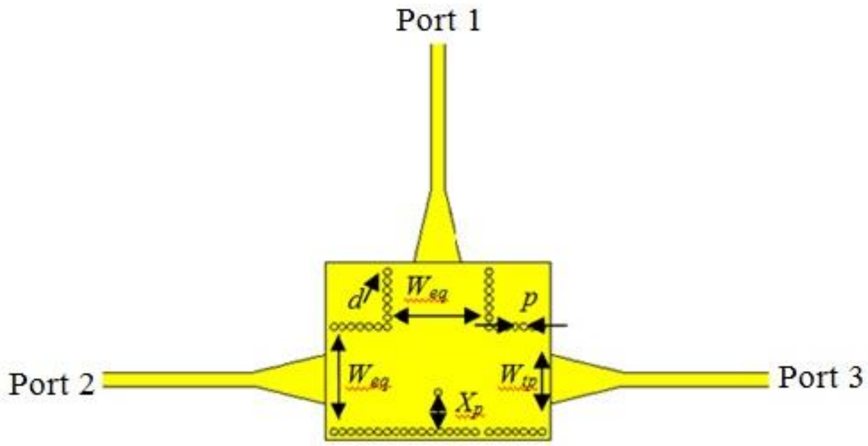


Figure 1. SIW power divider configuration

For SIW method, the mode that will be appeared is the TE_{10} modes as the dominant mode. The dimension for designing the Ku-band power divider can be obtained from the mathematical expression written as (1) and (2) [14]:

$$f_{c(TE10)} = \frac{c}{2\sqrt{\varepsilon_r}} \cdot \left(W - \frac{d^2}{0.95 \cdot p} \right)^{-1} \tag{1}$$

$$W_{eff} = W - \frac{d^2}{0.95 \cdot p} \tag{2}$$

where c, ε_r, W, d and p are the speed of light, dielectric permittivity of the substrate, the width of the SIW, diameter and the separation between the via holes respectively.

In order to minimize the signal leakage between vias holes, the via holes design must follow the following parametric conditions written as expression (3), (4), and (5) [15-16]:

$$p/\lambda_c < 0.25 \quad (3)$$

$$d < \lambda_g /5 \quad (4)$$

$$d < p < 2d \quad (5)$$

where λc and λg is the cutoff wavelength and the guided wavelength respectively.

The metallic via hole is placed at the centre between port 2 and port 3. According to fundamental of the waveguide transmission theory, the metallic via hole is equivalent to a susceptance. The changing of the position of Xp can change the reflecting and scattering signal of the input signal. Three tapered lines are chosen as the transition between the microstrip line and SIW for each of the input and output port to provide the matching to the 50 Ω microstrip line.

3. SIMULATED AND MEASURED RESULTS

The SIW power divider is constructed using a RO4003C substrate having εr=3.38 and the thickness=0.508 mm. The centre via, X_p has been added to achieve better return losses performance. Some parametric studies are performed on X_p to obtain the overall optimized performance on the proposed SIW power divider.

The distance of the metallic via hole to the bottom vias, X_p has been adjusted to 2.78 mm and 4.83 mm and the simulated results are shown in Figure 2. When X_p is at 2.78 mm which is below the centre of the output ports, the bandwidth of reflection coefficient, S11 is increase over a wide band while the performance is degraded when the X_p at 4.83 mm. With this value, the operational bandwidth is limited to the frequency range of 13.15 GHz to 15.32 GHz. Therefore the value of X_p should not be more than ½ of the W_{eq} value from bottom vias.

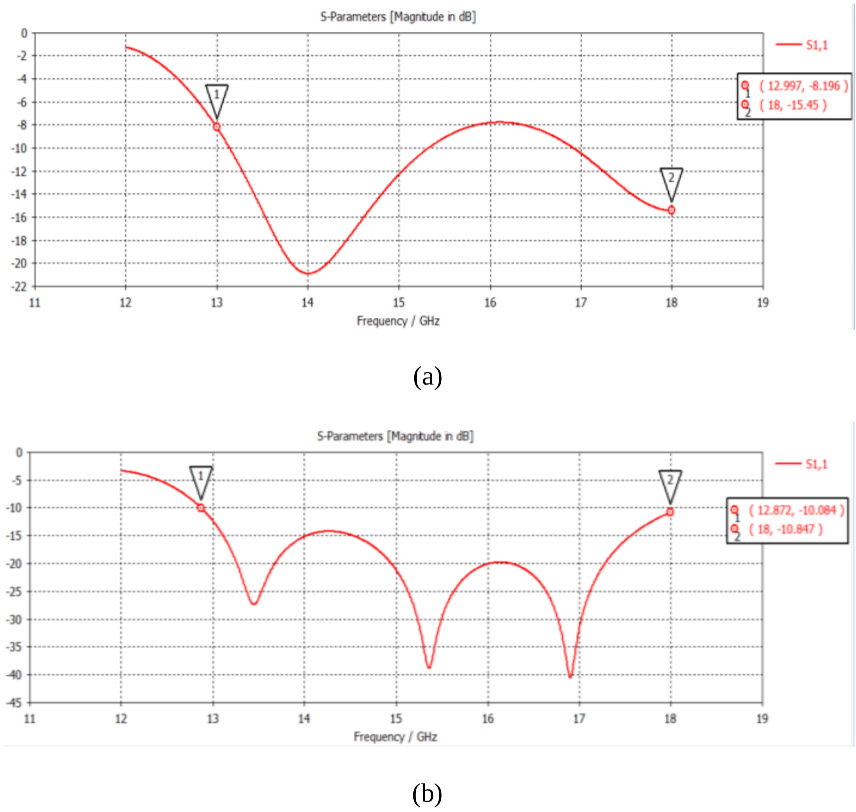
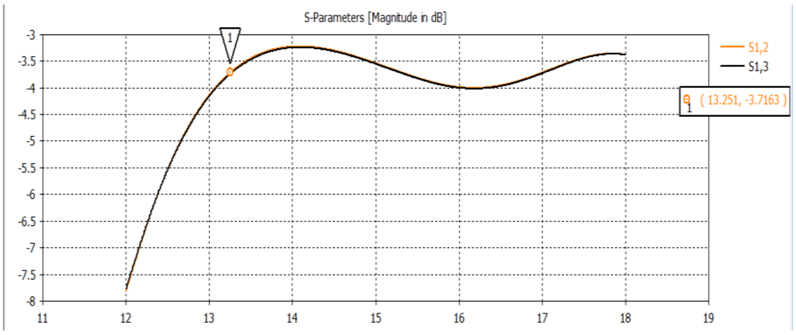
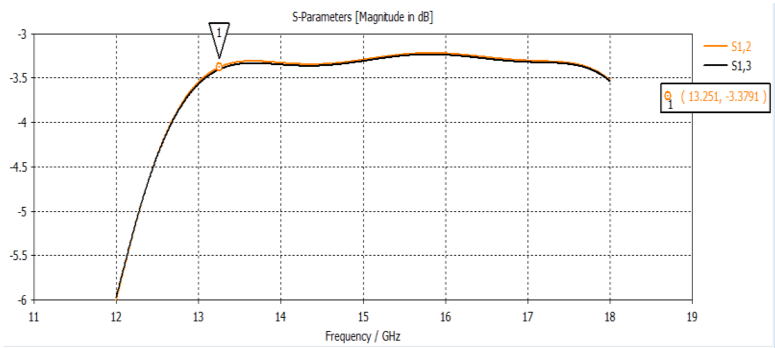


Figure 2. Simulation results of S_{11} (a) After X_p adjusted to 4.83 mm and (b) After X_p adjusted to 2.78 mm



(a)



(b)

Figure 3. Simulation results of S_{12} and S_{13} (a) After X_p adjusted to 4.83 mm, (b) X_p adjusted to 2.78 mm

The results for insertion loss S12 and S13 are shown on Figure 3. When X_p is at 4.83 mm, the signal achieved is -4 dB ±0.7 dB across frequency range of 13.15 GHz to 18 GHz. After X_p is adjusted to 2.78 mm, the insertion loss is improved to -3.3 dB ±0.2 dB accross 13.2 GHz to 18 GHz. The signal level achieved is better by which the signal is more constant which is have a flat coupling response.

After the parametric study, the dimensions of the SIW T-junction power divider are determined. Table 1 shows the optimised dimensions of SIW power divider. After that, the SIW power divider is fabricated to verify the results. The fabricated SIW power divider is shown in Figure 4. Comparison between the simulation and measurement results is shown in Figure 5.

Table 1. Parameter values of SIW T-junction power divider

Parameter	W_{eq}	W_{step}	d	p	X_p
Dimension (mm)	8.159	4.024	0.6	0.7	2.78

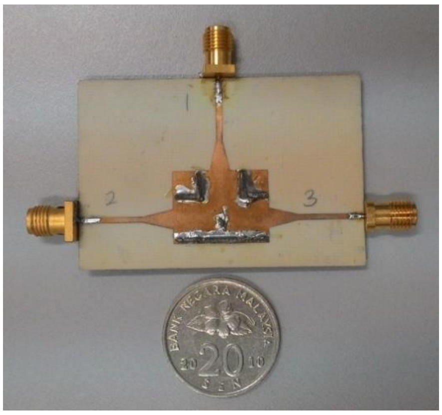
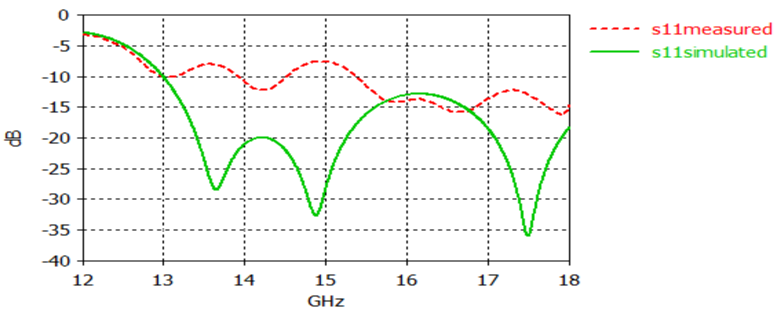


Figure 4. Fabricated SIW power divider



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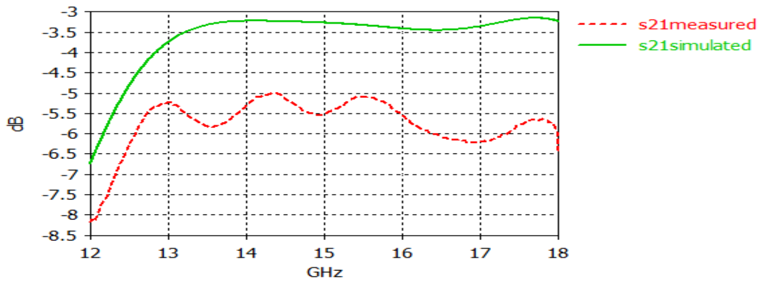
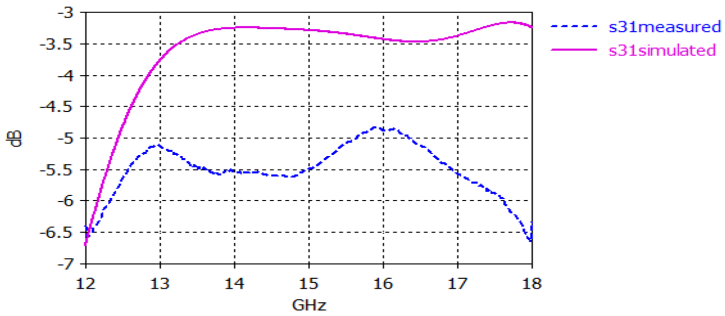


(b)



(c)

Figure 5. Comparison of SIW power divider simulation and measurement results (a) Return loss at Port 1 (S_{11}) (b) Insertion loss at Port 2 (S_{21}) (c) Insertion loss at Port 3 (S_{31})

The simulated results of S_{21} and S_{31} are about -3.1 ±0.4 dB across the frequency range of 13.5 GHz-18 GHz, which shows an equal power division between port 2 and 3. The simulated return loss at port 1 is better than is 10 dB across 13 GHz to 18 GHz while the measured result of S_{11} indicates an operational frequency range of 15.4 GHz to 18 GHz. The measured results of the fabricated SIW power divider are slightly degraded about 2 dB loss for both S_{21} and S_{31}.

The main losses occurred in the measured results is due to the connector loss. The imperfect fabrication also contributed to the loss and imbalance amplitude of power division of the SIW power divider measurement results. An SIW transmission line is fabricated to investigate the loss caused by the connector. The fabrication of the SIW line is shown in Figure 6. The results of the simulation and measurement are shown in Figure 7.

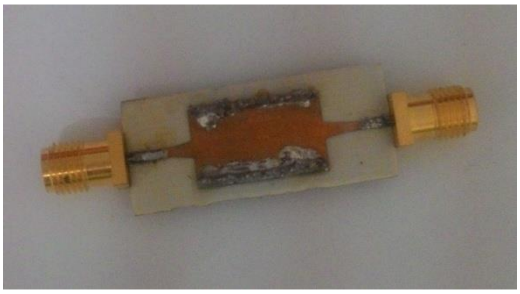
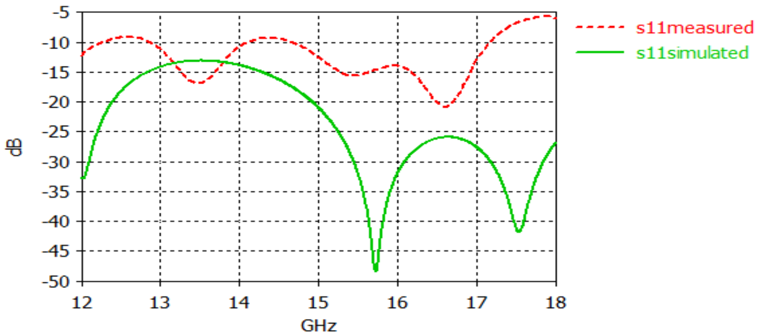
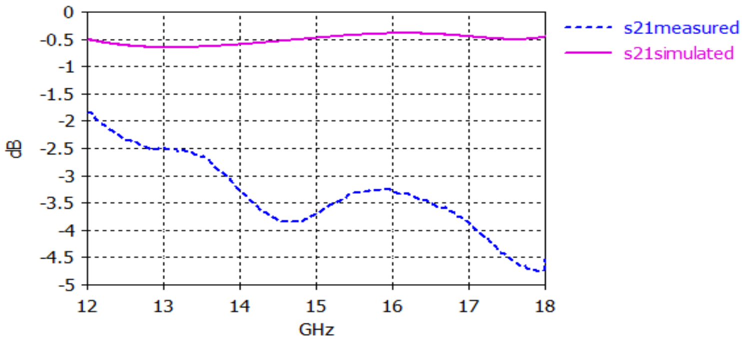


Figure 6. Fabricated SIW transmission line



(a)



(b)

Figure 7. Comparison of simulated and measured results (a) S_{11} (b) $S_{21}$of SIW transmission line

As depicted in Figure 7, the measured S_{21} result of the connector is degraded about 2 dB insertion losses and more significant at high frequency. The measured result of S_{11} result also indicates degraded reflection coefficient performance of the fabricated connector.

Comparison of the SIW power divider to the previously researched SIW power divider is made to show the advantage of the design. The comparison between the simulation insertion losses of the SIW power dividers is shown in Table 2. The comparisons show that the proposed SIW power divider has lower insertion loss.

Table 2. Comparison of SIW power dividers performance in simulation

References	Operating Frequency (GHz)	Substrate	Topology	Insertion loss (dB)
[3]	18-26.5	Not available	T-junction	3.45 ±0.5
[5]	8.5-16	RO4350	Y-junction	3.9 ±0.2
[6]	8.25-12.25	RT5880	Half-mode with slots and resistor	4.0 ±0.5
[7]	8-9.4	RT5880	T-junction with slots	4.0 ±0.3
This work	13.5-18	RO4003	T-junction	3.1 ±0.4

4. CONCLUSION

A Ku-band T-junction SIW power divider has been presented. The additional via successfully enhanced the insertion loss performance. As a result, the simulated input return losses at port 1 are better than 27 dB and features equal power division of about -3.1 dB ±0.4 dB at both output ports across frequency range of 13.5-18 GHz. The SIW power divider has been fabricated, and the measurement results show acceptable performances. An additional SIW transmission line has been simulated and fabricated to analyze the connector loss to verify the degraded performances of the measured results caused by the connector performances.

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