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A New Miniaturized Wilkinson Power Divider Based on a New HMSIW and CRLH-TL Cells

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Abstract

Objectives: In this study, two new power splitters integrated with a novel half mode substrate integrated waveguide (HMSIW) and composite right/left-handed transmission lines (CRLH-TL) cells are presented, realized and compared to a conventional Substrate Integrated Waveguide (SIW) one. **Methods:** The SIW technology is characterized by a high Q factor and a low return loss, but it suffers from the massive size particularly in low frequencies bands, so to achieve practically 50% miniaturization in size with keeping the high performances of the SIW technique, HMSIW origins from SIW has been utilized. otherwise, so as to reduce the HMSIW device, size, Composite Right/Left-Handed Transmission Lines (CRLH-TL) cells are applied. The designs are printed on a Roger RT/duroid 6010 and performed within an HFSS environment based on the finite element method (FEM). Simulations and measurements of the three power dividers are presented over a frequency band from 2.2 GHz to 2.6 GHz. **Findings:** The novel proposed component achieves about 70% and 90% of size reduction compared to, respectively, the HMSIW and SIW power splitters. The simulated and measured results are in close agreement. **Application:** Compared to the SIW power divider and the HMSIW one the novel proposed device is characterized by a compact size and an easy fabrication process. So that it will enable a convenient reduction of size, loss and cost in millimeter-wave and microwave systems.

Keywords: Power Divider, HMSIW, SIW, CRLH-TL Cells, Tapered Transition

1. Introduction

Power dividers are considered as an essential cell of microwave and millimeter-wave devices. It is a kind of microwave circuit that can split the signal with an equal or unequal power division ratio. It is a fundamental element for modern communications systems operations that require processing and routing of multiple copies of a signal. It is widely used in RF and millimetre-wave transmitter, phased array radars, satellite communications. With benefits of compact size, high integration and low-cost numerous strip-line and micro-strip power dividers have been studied and proposed.[1–3] Yet the structures based on those techniques even suffer from some limitations as the high loss and poor Q factor, particularly at very high operating frequencies. Recently, a novel planar circuit called substrate integrated waveguide (SIW) has appeared as a sort of rectangular dielectric-filled waveguide.[4,5] In an SIW, bilateral edge walls are realized by using two arrays of metallized via holes in a planar substrate. It is considered as an excellent platform to improve several micro-wave and millimeter-wave components as power splitters, antennas and couplers owing to its High-Q properties, low insertion loss,[6–8] but the huge dimensions of an SIW affects the integration of planar devices and opposes with some practical limitation of devices.[9,10] Thus, HMSIW was presented and investigated as a novel guided-wave structure.[11–13]

Considerably decreased the size (by nearly 50%) with high performances that can be provided by the HMSIW technique. In fact, the SIW structure can be bisected transversely into halves using a fictitious and symmetrical

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magnetic wall, so each half becomes an HMSIW structure and can support the half guided wave modes.[14,15] Its dominant mode is approximately half of the TE mode in an SIW. In this case, it is considered a promising approach that fulfills modern microwave communication system requirements. To further reduce the dimensions of the proposed HMSIW devices, CLRH-TL cells are used.[16–18] It is one of various technics that have been proposed concerning the miniaturization of conventional power divider structures.[19,20]

In this study, a new approach consists of integrating a novel proposed CRLH –TL cell on an HMSIW structure to optimize a new compact power divider operating at 2.45GHz. It brings about a miniaturization of nearly 85% and an easier fabrication process compared with the traditional SIW one.

The rest of this study is organized as follows: In Section. 2, SIW and HMSIW concept and designs are briefly presented. In section. 3 the novel miniaturized power divider including the novel proposed CRLH-TL cell is detailed. Section. 4 provides the designs, simulation, and measurement discussion.

2. SIW Power Divider

2.1 The Relationship between Microstrip SIW and HMSIW Technologies

If an SIW is bisected into two halves within the symmetric plane as shown in Figure 1, the obtained aperture is

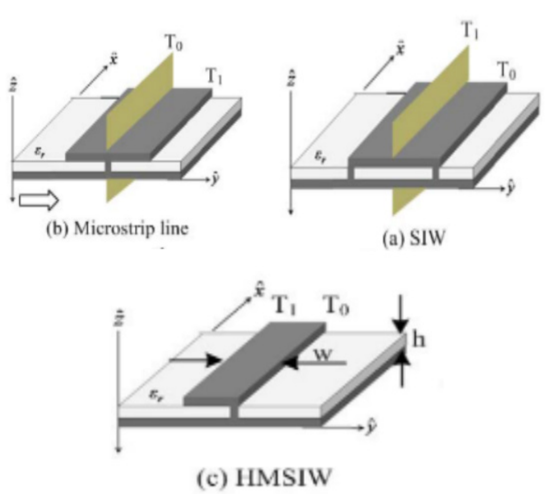


Figure 1. The relationship between Micro-strip line, SIW and HMSIW.

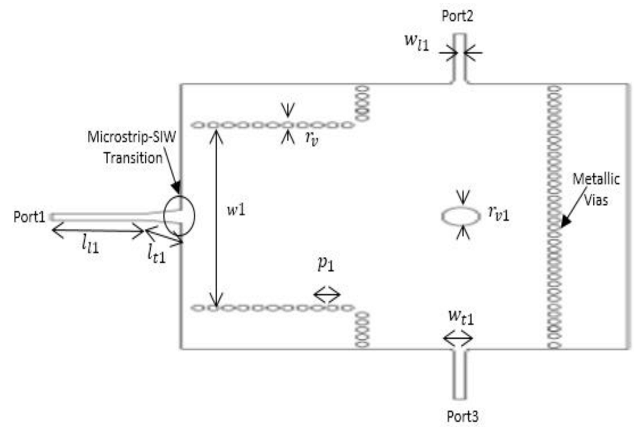


Figure 2. SIW power divider.

similar to a magnetic wall. In each obtained half the dominant mode is similar to one half of the dominant TE10 in an SIW. The electric field is slightly out diffused to satisfy its boundary condition. Also, a microstrip line can be considered like an HMSIW if it is terminated by a short-circuited plane in the center.

2.2 Configuration and Simulation Results

The layout of the SIW power splitter is depicted in Figure 2. It is the well-known structure of a conventional Wilkinson power splitter. It is composed of two perpendicular guides constructed by two rows of metallic via with a diameter of 1.2 mm and a period of 1.4 mm. The via with radius rv1 located at the intersection of the symmetrical axes of the three guides is used to control the coupling between output and coupled ports. The scattering and reflecting parameters of the input signal can be fixed by changing the position and diameter of that metalized via hole. The tapered microstrips-to-SIW are utilized for the coaxial connections for the 3-port during the measurement step and to facilitate the integration of passive and active components. Also, the tapered transitions are used for matching the impedance between the SIW and the 50-ohm microstrip line. The 50-ohm microstrip line can well excite a TE10 mode, thus both micro-strip and SIW line have approximated electric field distribution. As shown in Figure 1 are the width and length of the tapered transition. Those parameters are optimized to have impedance characteristics of 50 ohms and 35 ohms. The cut-off frequency of the SIW power divider is designed at 2.45 GHz. The initial dimension's values are calculated by the empirical equations (1) and (2).[21,22] Ports 1, 2 and 3 are, respectively, the input, through and coupled ports.

The dimensions of the SIW power splitter are depicted in Table 1. The SIW power splitter can achieve a return loss better than 10 dB in the frequency range from 2.3 GHz to 2.45 GHz as shown in Figure 3. The through output and coupling parameters are -3.2 ± 0.2 in the same frequency range.

$$W = W_{SIW} - 1.08\frac{D^2}{s} + 0.1\frac{d2}{W_{SIW}} \tag{1}$$

$$f_c = \frac{1}{2W\sqrt{\varepsilon_r}} \tag{2}$$

Where fc represents theF cut-off frequency of the rectangular waveguide and is the substrate relative permittivity. W is the corresponding metallic rectangular waveguide width, d is the metallic via holes' diameter, and 1 is the distance between two successive vias.

Table 1. Dimensions of the SIW coupler

Symbol	Value (mm)
1	6
1	2
1	60
	0.6
1	1.2
1	0.7
1	1.5
1	1.4

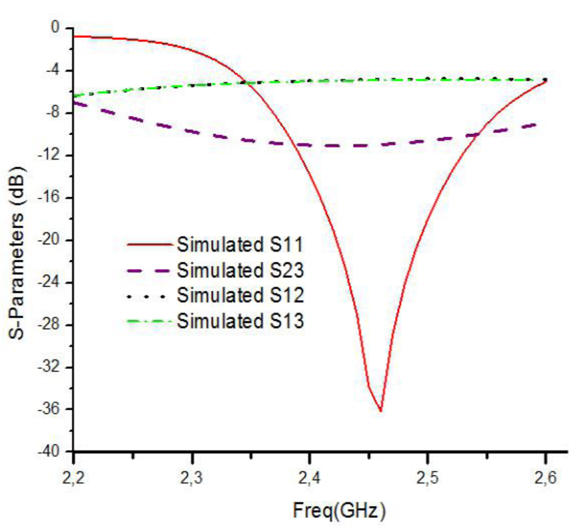


Figure 3. Simulated S-parameters of the SIW power divider.

3. HMSIW Power Divider

In order to miniaturize the SIW power splitter, a new structure is designed and fabricated. The layout of the proposed configuration is described in Figure 4 where ports (1) (2) and (3) are the input, through and coupled ports respectively. The same substrate with relative permittivity of 10.2 and a substrate thickness of 0.635 mm is used. The measurements are accomplished using the Agilent technology E5071C network analyzer. Tapered microstrip to HMSIW transition having impedance characteristics Z_0 *and* $Z_0/\sqrt{2}$ are also used here. This new configuration is a mix of SIW and HMSIW techniques. In fact, the input port is based on the SIW technic. To reduce the structure size, the same width of the SIW input port is kept to form the two output ports, the idea here is to add metallized vias in the symmetrical plane of the input guide so that two HMSIW are obtained, each of which will form an output port. So that the new proposed structure is made up of two parts, an SIW part that contains the input port and an HMSIW part that has both output ports. This configuration permits to reduce the SIW power splitter size by eliminating the second SIW and by minimizing a large number of metalized holes, which reduces circuit complexity and facilitates the manufacturing process. The simulation result presented in Figure 5 shows that in

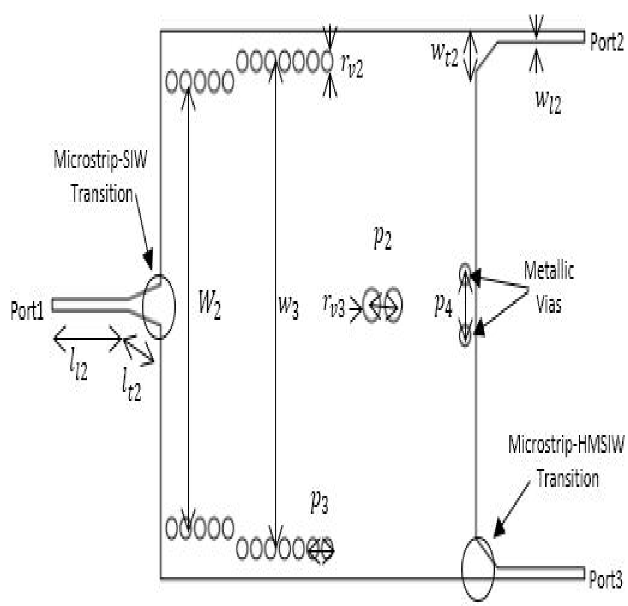


Figure 4. The layout of the HMSIW coupler.

the frequency band from 2.4 GHz to 2.6 GHz, the return loss S11 better than 10 dB. The phase difference between port 2 and port 3 is around 0° in the total frequency range (Figure 6) also through output and coupling parameters are −3.4 ± 0.5 dB within the frequency band from 2.35 GHz to 2.6 GHz (Figure 6). The main drawback of this proposed circuit is the isolation performance between the

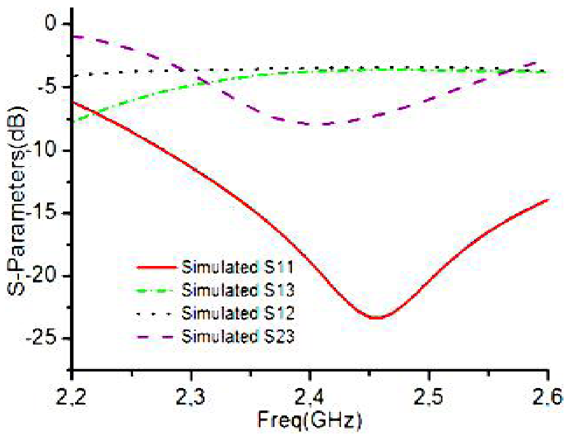


Figure 5. Simulated S-parameters of the HMSIW power divider.

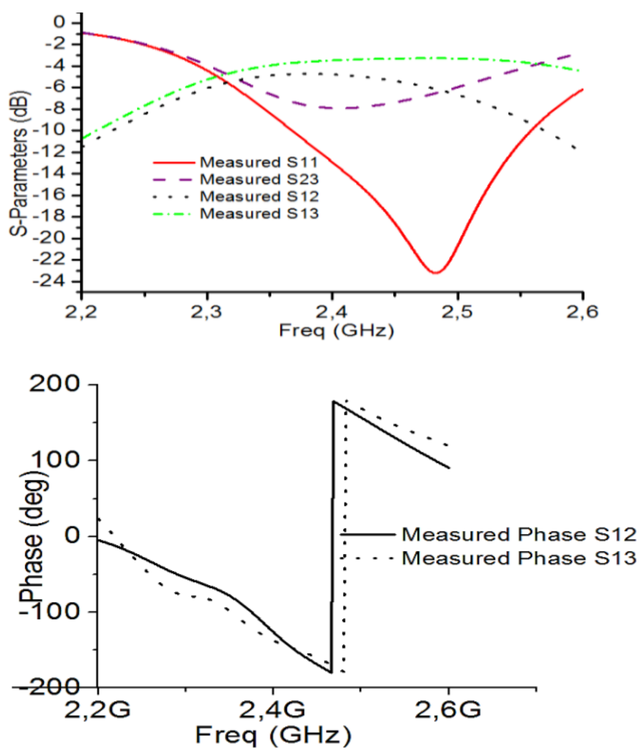


Figure 6. Measurements of The (a) S-parameters and (b) Phase difference of the HMSIW power divider.

Table 2. Dimensions of the HMSIW coupler

Symbol	Value (mm)
2	6
2	2
2	30
3	31.5
2	0.6
3	0.8
2	0.7
2	1.5
2	1.5
3	1.2
4	2.5

two output ports. It is only about 7 dB. It is needed to be ameliorated in our future work. The width of the HMSIW power splitter is approximately half of the SIW one. The HMSIW power divider dimensions are given in Table 2.

4. HMSIW Power Divider with CRLH-TL

4.1 The Proposed CRLH-TL Cell

Compared to the huge size of SIW configurations, the circuit complexity and the high cost, the HMSIW technology can be considered as a promising approach that allows reducing those limitations, however, its dimensions still also large towards the new micro-wave and millimeter-wave circuit and system requirements. That's why in this work to further reduce the HMSIW size a new CRLH-TL cell is presented and utilized. The inner surface of the HMSIW power splitter was exploited to implement CRLH-TL cells. As seen in (Figure 7a), the slots are altered to become meander-shaped with a = 5 mm, b = 1.2 mm, c = 3 mm and d = 0.5 mm. The unit cell length p is much smaller than the guided wavelength λg (p ≪ λg) because the CRLH-TL operates in the regime of the long-wavelength.

(Figure 7b) and (Figure 7c) illustrate the HMSIW and the CRLH-TL electric field distributions at the plane z = 0. These simulations show that the maximum electric fields are concentrated in the inputs and outputs of those transmission lines. The electric field leakage near the microstrip transition is more significant than in the via

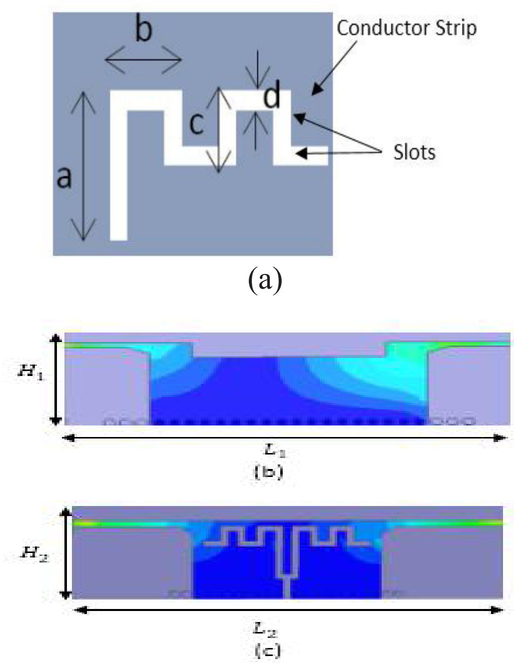


Figure 7. (a) Front view of micro-strip CLRH-TL cell Layout of the two transmission lines including the simulated field distributions of b) HMSIW, c) HMSIW with CRLH-TL.

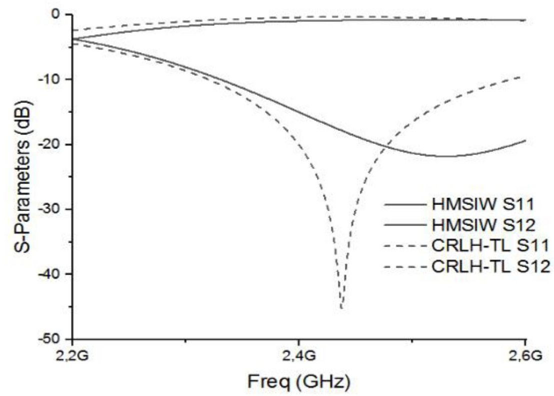
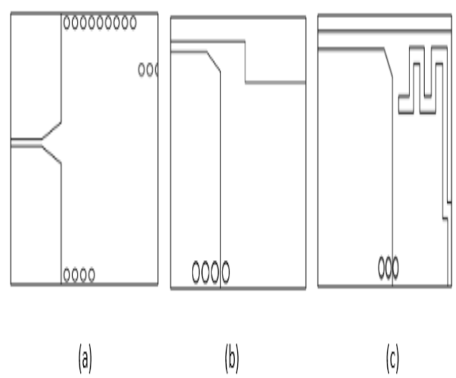


Figure 8. Simulated S- parameters the HMSIW and HMSIW with CRLH-TL.



L_s	4
p_s	0.55
W_4	12

Figure 9. Evolution of the process of miniaturization techniques.

walls. Via holes contribute to better bind the electric field distribution along the transmission line.

In (Figure 8) the S-parameters simulation results of the HMSIW and HMSIW with CRLH-TL are plotted. The simulated return loss across the frequency band from 2.3 to 2.6 GHz is better than 10 dB for the two circuits and the insertion loss is 0.8 ± 0.5 dB.

To conclude, because of the large width of an SIW (Figure 9a) and the significant number of the used metallic vias, this technique cannot be considered as a good choice especially at low working frequencies and for the multiport circuit. So, by bisecting an SIW transversally, we can benefit from the advantages of the obtained HMSIW structure (Figure 9b). The size reduction until the half and the decrease of the metallic vias number make it a good choice in this case. Moreover, by adding the CRLH-TL cell as shown in (Figure 9c), the HMSIW can be considerably miniaturized. In the next section, the CRLH-TL concept will be applied to an HMSIW coupler to show its advantages and limits as a technique of miniaturization.

4.2 Simulation and Measurement Results of the Proposed Power Divider

The layout of the new proposed structure is shown in Figure 10 where ports (1) (2) and (3) are the input, through and coupled ports respectively. The same substrate with relative permittivity of 10.2 and a substrate thickness of 0.635 mm is used. Also, Tapered microstrip to HMSIW transition having impedance characteristics 0 and $0/\sqrt{2}$ are also used here. This new configuration is a mix between HMSIW and CRLH-TL techniques. The physical dimension of the HMSIW power splitter can be reduced using a slow-wave mode of meandered-shaped slots. In this case, the new proposed CRLH-TL has been added to the inner surface of the HMSIW power divider. Those cells are cascaded symmetrically to obtain the new design of our miniaturized circuit. Simulation and measurement results presented in Figures 11 and 12 show that in the frequency

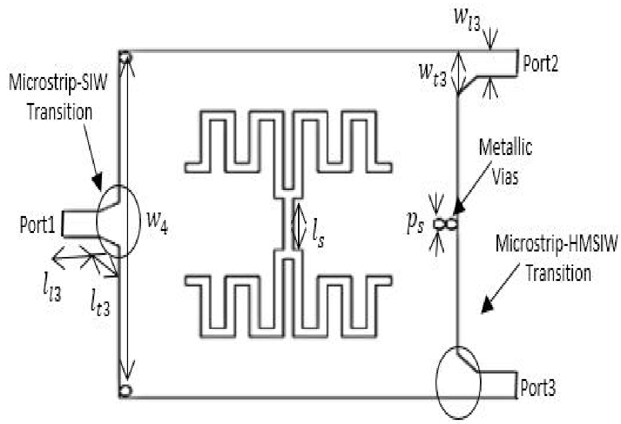


Figure 10. (a) The Lay out of the HMSIW power divider using CRLH-TL cell (b) The proposed CRLH-TL cell.

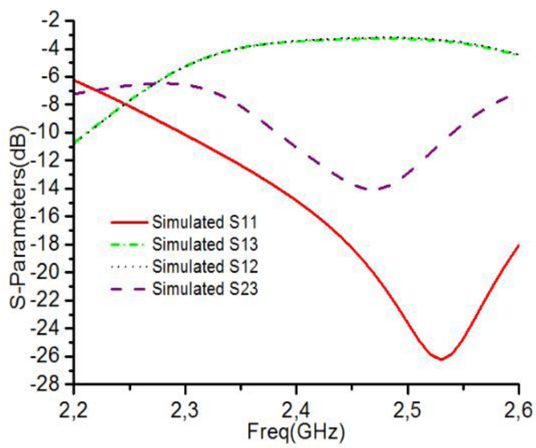


Figure 11. Simulated S-parameters of the HMSIW power divider with CRLH-TL.

band from 2.4 GHz to 2.6 GHz the return loss S11 better than 10 dB. The phase difference between port 2 and port 3 is around 0° in the total frequency range (Figure 12) also through output and coupling parameters are −3.4 ± 0.5 dB within the frequency band from 2.35 GHz to 2.6 GHz. The improvement of the isolation performance between the two output ports is the significant contribution of this optimised circuit. It is better than dB in the frequency band from 2.35 GHz to 2.6 GHz.

The dimensions of the HMSIW power dividers are given in Table 3:

5. Comparison

From the above-obtained results, it is observed that for the three configurations we have a good matching, an equal

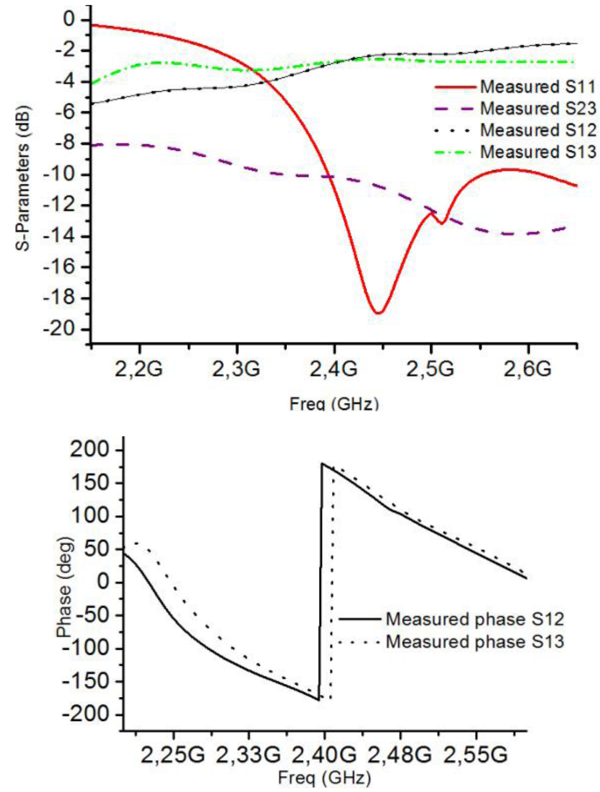


Figure 12. Measured (a) S-parameters and (b) phase difference of the HMSISIW power divider using CRLH-TL cells.

Table 3. Dimensions of the HMSIW with CRLH-TL cells

Symbol	Value (mm)
3	6
3	2
3	0.8
3	1.5

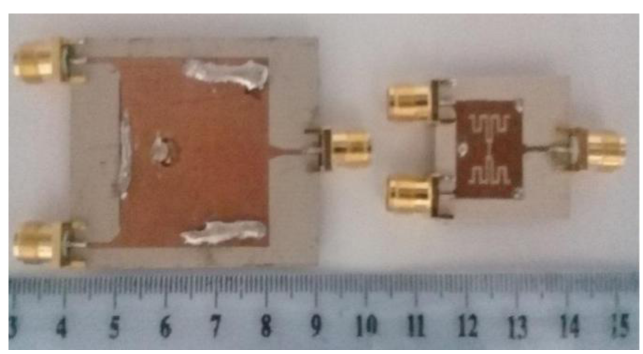


Figure 13. Photograph of the two proposed power dividers.

Table 4. Power dividers performances comparison

	In[20]	In[17]	In[8]	This work
Topology	SIW-DGS	Extended CRLH-TL-SIW	SIW	CRLH-TL –HMSIW
Freq [GHz]	8 to 9.4	3 to 6.5	8.5 to 11.2	2.2 to 2.6
Return Loss (dB)	<–17	<–16	<–10	<–20
Power Equality (dB)	4.2 ± 0.3	4.5 ± 0.5	3.25 ± 0.5	3.1 ± 0.5
Total width (mm)	32	15.1	12.47	14
Total area (mm * mm)	32×46	15.1×28.34 (excluding access lines)	12.47×12.47 (Just the ring part)	14×28

power division also, the two output ports exhibit phase balance in the total frequency range. It is obvious that the HMSIW power divider with CRLH-TL cells presents good performances compared to the two other structures. A return loss better than 10 dB is achieved within the frequency band from 2.3 GHz to 2.6 GHz as seen in Figure 6. Also, the output and coupling parameters, for the SIW structure are very close to the theoretical value −3 dB at over 75% of the bandwidth whereas those values are −3.2 dB and −3.5 dB at over 50% of the bandwidth for the two others power dividers. For the three structures, a bandwidth of 200 MHz is achieved and the phase difference between S13 and S14 is 90° ± 2°. It can be observed that the simulated and measured results are in close agreement. Because of the added SMA connector, the fabrication tolerance, the manual metallization of vias, small degradations between simulations and measurements can be observed. Moreover, the main drawback of an SIW and an HMSIW component is their very big dimensions and the big number of the used metallic vias. The SIW power divider size is 65 mm × 82 mm. The HMSIW power splitter size is 33 mm × 49 mm while the HMSIW one using CRLH-TL occupies an area of 14 mm × 28 mm.

A photograph of the two realized power splitter is shown in Figure 13 clarifying the important contribution of the CRLH-TL cells to miniaturize the SIW and HMSIW structures. In Table 4, the performances comparison between our proposed power splitter and some cited structures are illustrated. It can be observed that the insertion losses of the newly proposed device in this work are relatively low. Also, the band-pass is relatively compact. In addition to that, the much lower operating frequency of our proposed circuit has a smaller size compared to the cited ones.

6. Conclusion

Two novel power dividers based on HMSIW and HMSIW with CRLH-TL cells are designed fabricated and presented in this work. Compared to a conventional SIW power divider and the HMSIW one, the novel proposed device based on CRLH-TL cells is characterized by an ameliorated isolation performance between the two output ports. Its value is better than 10 dB in the frequency band from 2.2 GHz to 2.6 GHz. Moreover, it is characterized by a compact size and an easy fabrication process. So that it will enable a practical size, loss and cost reduction in millimeter-wave and microwave systems.

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