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Compact QMSIW Diplexer with High Isolation

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Abstract—A novel substrate integrated waveguide (SIW) planar diplexer with very high isolation is presented. It is formed by two quarter mode substrate integrated waveguide (QMSIW) cavity resonators which are designed individually and combined through a T-junction. The diplexer channels are 13% and 15% relative bandwidths at 2.35 GHz and 3.5 GHz, respectively. Within the passband, the return losses are better than 22 dB and 25 dB with the insertion losses of 0.8 dB and 0.5 dB, in the lower and higher channels. Meanwhile, the diplexer exhibits a better than 42 dB isolation, indicating high isolation between the two channels. The measured results of the fabricated diplexer agree well with the simulated ones.

1. INTRODUCTION

With the rapid development of science and technology, microwave communication technology is widely used in modern wireless communication systems. Diplexers are indispensable components in the RF front end of most multiservice and multiband communication systems to reduce the number of antenna.

In recent years, compact millimeter wave diplexers are usually designed based on waveguide or metal cavity with excellent performance. However, the design suffers from disadvantages such as being bulky, costly and difficult to fabricate. Moreover, it cannot be integrated with the mm-wave planar integrated circuits of the transceiver. Therefore, how to design the diplexers with high isolation and good selectivity is currently of great interest. Substrate integrated waveguide (SIW) technology is a promising candidate to overcome these drawbacks. It provides compact, easy to fabricate, flexible and cost-effective mm-wave diplexers while preserving most of the advantages of the conventional metallic waveguides, namely, complete shielding, low loss, high quality-factor and high power-handing capability. Thus, several diplexers have recently been proposed in SIW technology. In [1], SIW diplexers with branching port configurations are proposed where the angle between the two output ports is 90°. A C-band diplexer with moderate insertion losses is designed in [2] based on inductive SIW filters. T-junction diplexers are presented in [3–5] with output port angles of 180°. The mode-matching technique is used to analyze and design a K-band SIW diplexer in [6].

In order to further reduce the size of the components, a quarter mode substrate integrated waveguide (QMSIW) [7] as an alternative structure of SIW was proposed. Fig. 1 illustrates the QMSIW cavity, which is generated by bisecting the SIW cavity twice to four sections along two fictitious magnetic walls while preserving identical cutoff frequency and propagation characteristics, reducing circuit size by approximately 75% [8]. It nearly preserves a quarter of the original field distribution of the SIW cavity.

In this paper, a compact quarter-mode SIW diplexer with high isolation is proposed. The diplexer with the quarter mode induces low in-band insertion loss and rapid out-band falloff characteristics, where the tradeoff among the loss, selectivity and isolation is made for high performance requirement.

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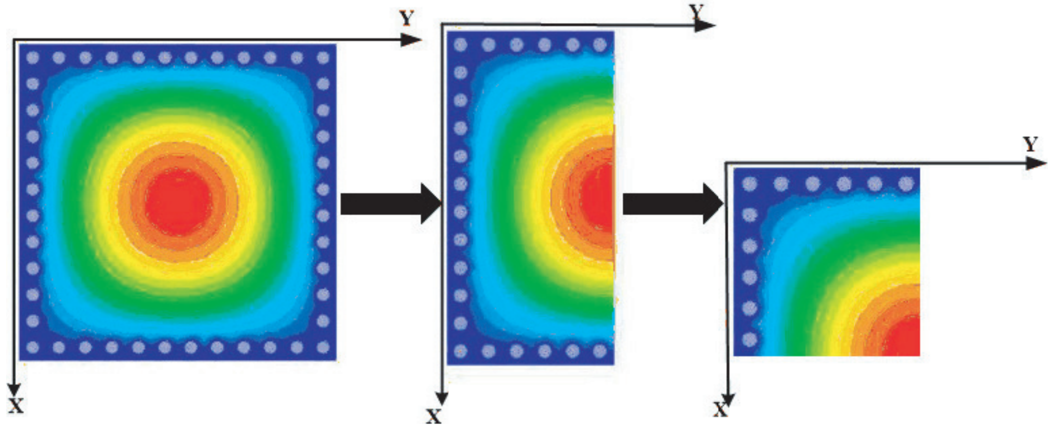


Figure 1. Electric filed distribution of full-mode SIW, HMSIW and QMSIW cavities.

The whole structure is fabricated using low cost single-layer PCB process. As a result, not only the size, weight and cost of the components are reduced, but also the manufacturing repeatability and reliability can be enhanced. Electromagnetic analysis of the structure is performed with the commercial full-wave solver Ansys HFSS 15.0. The fabricated filter is measured by an Agilent 8722ES network analyzer. Finally, the results are quantitatively compared to the previous results in references.

2. SIW FILTER DESIGN

2.1. Quarter Cavity Resonator

The quarter-mode substrate integrated waveguide (QMSIW) concept is proposed to further reduce the size of SIW components. It is realized by bisecting the SIW twice along the perfect magnetic wall. Therefore, it is a quarter of SIW resonator cavity. Fig. 1 shows the comparison of electric field distribution in full-mode SIW, HMSIW and QMSIW cavities. It is found that the top metal wall and the metal vias of three quarters of the structure are removed, while nearly a quarter of the original field distribution of the SIW structure can be held. The dominant resonator mode is TE_{101} mode, and its resonance frequency is given by:

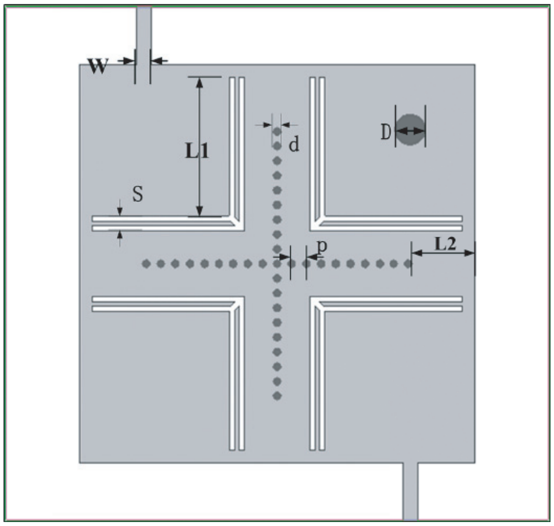
$$f = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{\pi}{a_{\mathrm{eff}}}\right)^2 + \left(\frac{\pi}{b_{\mathrm{eff}}}\right)^2} \tag{1}$$

$$a_{\mathrm{eff}} = a - \frac{d^2}{0.95m}, \quad b_{\mathrm{eff}} = b - \frac{d^2}{0.95m}, \tag{2}$$

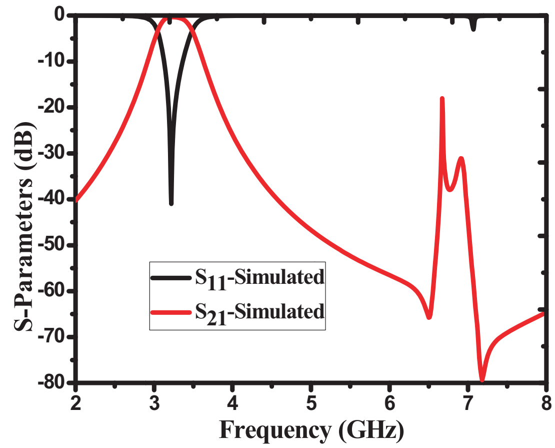
where c is the light speed in free space; ε_r is the relative dielectric constant; μ_r is the permeability; a and b are the length and width of the cavity, respectively; d is the diameter of metallic vias; m is the distance between the centers of two adjacent vias.

2.2. The Channel Filter

Based on [9], the channel filter is composed of four QMSIW square resonant cavities. Fig. 2(a) shows the geometrical configuration of the designed channel filter. The proposed channel filter with asymmetric input/output feed line structure exhibits extremely wide stopband performance. Some meandered H-shaped slots are etched on the QMSIW filter to change the current direction for size reduction. Its insertion loss at center frequency (3.25 GHz) is 0.3 dB and the return loss is better than 40dB. The simulation results are shown in Fig. 2(b).



(a)



(b)

Figure 2. (a) Configuration of the channel filter unit cell and (b) Simulated frequency responses of the proposed channel filter.

3. DIPLEXER DESIGN

3.1. Structure

Figure 3 shows the geometrical layout of the whole structure. The diplexer design begins with the design of the two channel filters. In both channels, four-pole QMSIW filters are proposed with the goal of having $|S_{11}| < -20\,\text{dB}$ in the pass-band. The two filters can be designed independently. At the same time, they are connected to a common input port through a microstrip T-junction, which has a stopband in the middle of the two passbands. This CPW-SIW transition is commonly used for

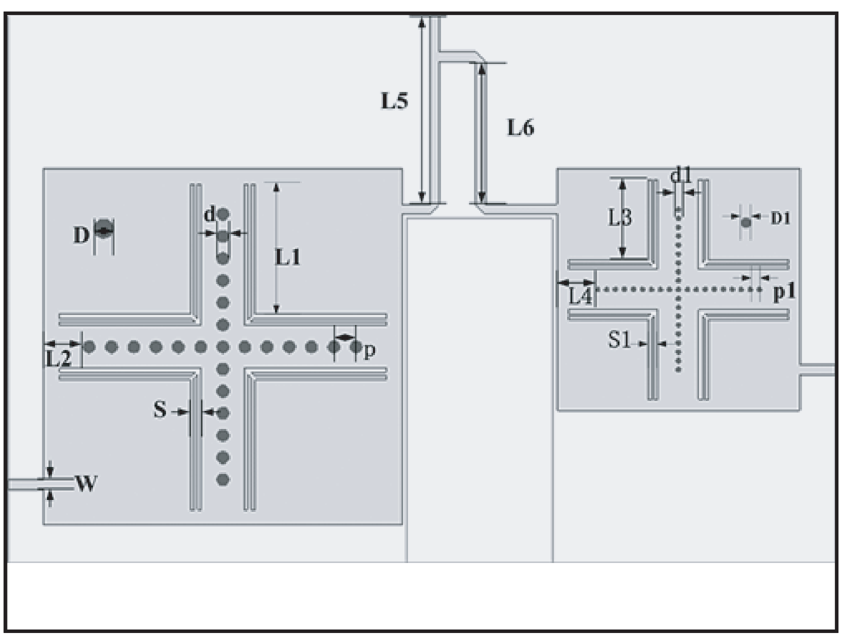


Figure 3. Configuration of the diplexer.

impedance matching in the SIW technology. A 0.254 mm thick Roger RT/Duroid 5880 with relative permittivity $\varepsilon_r = 2.2$ and dielectric loss tangent 0.0009 is used for implementing an S-band prototype with channel filters centered at 2.35 and 3.5 GHz, respectively. The bandwidth of lower channel is 300 MHz (13%), and that of higher channel is 500 MHz (15%).

3.2. T-Junction

Traditionally, a T-junction is used to combine the two filters. A T-junction for the opposite channels is adopted to enhance isolation and minimize channel filter interaction. The size of the T-junction will significantly affect the performance of the designed diplexer. Thus, it must be optimized at circuital level without any change of the independent channel filters design. It is a hard process due to multi-parameters to be optimized and the structure complexity. The optimization for the T-junction must be carefully carried out by using full-wave simulation. The structural parameters of the T-junction are also shown in Fig. 3.

4. FABRICATION AND MEASUREMENT

Based on the above analysis, the diplexer is experimentally fabricated on a substrate of Rogers RT/Duriod 5880. The final dimensions of this planar diplexer are presented in Table 1, where all dimensions are in millimeters. A photograph of the implemented diplexer is shown in Fig. 6 for compact size (68.9 mm × 45.7 mm × 0.254 mm). It is measured using an Agilent 8722ES vector network analyzer. Fig. 4 shows the reflection and transmission coefficients ($|S_{11}|$, $|S_{21}|$ and $|S_{31}|$ in dB) of the simulated and measured results, as well as the isolation ($|S_{32}|$) for the diplexer. As can be seen, the agreement between different sets of the data is very good. The measured two passbands are centered at 2.35 and 3.5 GHz with 3 dB bandwidth from 2.2 to 2.5 GHz and from 3.2 to 3.8 GHz, which are slightly narrower than the simulated results. The measured return losses at lower and higher bands are better than 20 dB, and the minimum insertion losses at two bands are approximately 0.8 dB and 0.5 dB, respectively. In addition, the stopband suppression for both channels is better than 40 dB, while a minimum isolation of 42 dB is obtained. As we know, the key point of diplexer is isolation when RX- and TX-band frequencies are in close vicinity. So the diplexer in this Letter can provide a satisfactory isolation. To better verify the performance of the diplexer, Fig. 5 shows the simulated and measured channel return losses ($|S_{22}|$ and $|S_{33}|$ in dB). The return loss at each band is better than 30 dB, which agrees well with the simulation. The minimum isolation between two channels is 40 dB, compared with 42 dB from simulations. These discrepancies can be attributed to the measurement procedure and limitations in the measurement setup. However, the overall agreement between these sets of data is good. Comparison between literatures [10–

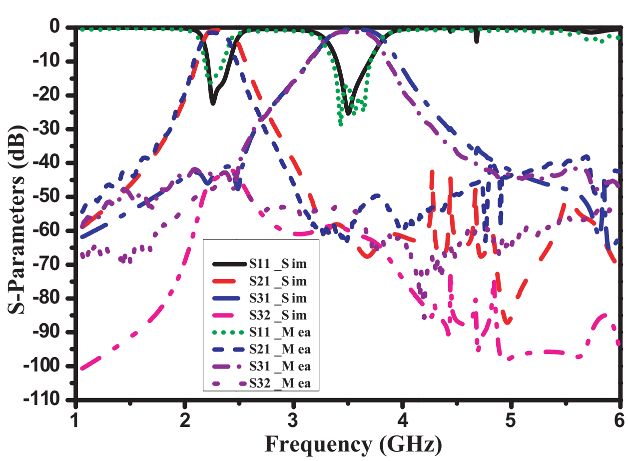


Figure 4. Simulated and measured frequency responses of the proposed diplexer.

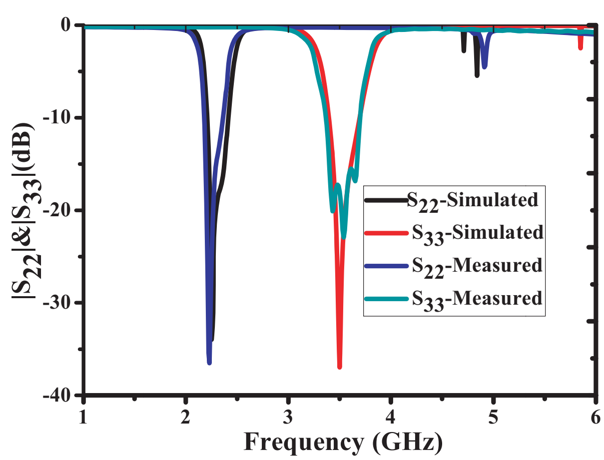
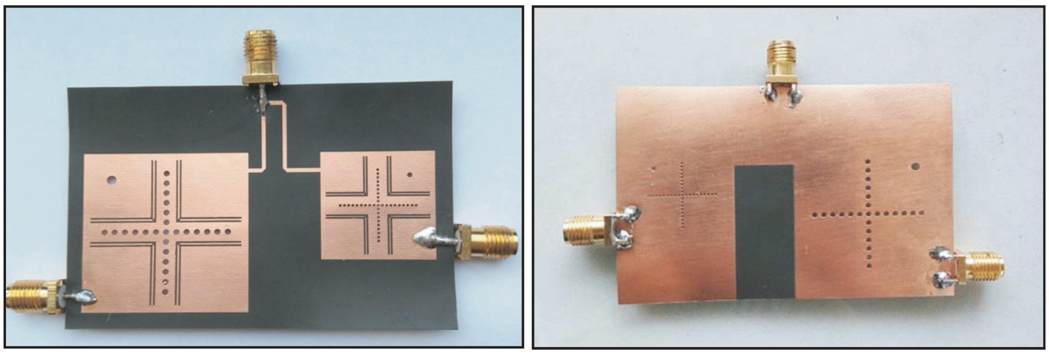


Figure 5. Simulated and measured return losses ($|S_{22}|$ and $|S_{33}|$).

13] and the proposed diplexer is listed in Table 2. In [10], a combline triplet diplexer with high rejection performance is obtained, but the circuit size is larger than the proposed one. In [11], the diplexer has a compact size with high selectivity and improved out-of-band rejection. However, its return loss is not very good (< 13 dB). The proposed diplexer [12] has reasonable size compared to other structures, but its isolation (< 20 dB) is not very good. Ref. [13] shows high isolation, while its insertion loss is far larger than the designed diplexer. It indicates that the designed diplexer is competitive to some degree, and the diplexer in this Letter is better than the referenced ones in terms of isolation. To the best of the authors' knowledge, this is the first QMSIW diplexer.



(a) (b)

Figure 6. Photograph of the fabricated diplexer. (a) Top view. (b) Bottom view.

Table 1. Dimensions of the proposed QMSIW bandpass filter (Unit: mm).

Parameter	Value	Parameter	Value	Parameter	Value
$L1$	10.9	$S1$	0.8	D	1.6
$L2$	3.3	d	1	$L4$	3.2
$L3$	6.7	$d1$	0.4	$L5$	15.8
W	0.78	p	1.85	$D1$	0.8
S	0.92	$p1$	0.74	$L6$	12

Table 2. Comparison between the proposed diplexer and the references.

	Freq (GHz)	IL (dB)	Isolation (dB)	Size ($\lambda_0 \times \lambda_0 \times \lambda_0$)
[10]	9.5/10.5	1.6/2.1	35	$2.04 \times 0.65 \times 0.053$
[11]	4.66/5.8	1.6/2.3	32	$0.27 \times 0.217 \times 0.008$
[12]	7.75/8.25	2.2/2.4	20	$1.44 \times 0.98 \times 0.022$
[13]	8/9	2.86/3.04	40	$0.83 \times 0.83 \times 0.064$
This work	2.35/3.5	0.8/0.5	42	$0.52 \times 0.34 \times 0.002$

5. CONCLUSION

Based on the characteristics of the quarter-mode cavity filter, a novel compact QMSIW diplexer with low insertion loss and high selectivity has been designed, fabricated, and measured. The results show that the isolation for the compact diplexer is high. The design procedure is very simple compared with the traditional ones. Its channels are 13% and 15% relative bandwidth at 2.35 GHz and 3.5 GHz, respectively. Device performance as shown by its measured insertion loss (approximately 0.8 dB and

0.5 dB in two bands), return loss (RL > 20 dB) and isolation (better than 42dB) is good. The slight frequency shift and losses are still in acceptable range. The simulated and measured results agree with each other, which confirm our concept. Therefore, it is promising in the use of communication system.

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