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High-isolation diplexer based on dual-mode substrate integrated waveguide resonator

Kaijun Song[1], Mou Luo[1], Cuilin Zhong[2] and Yuxuan Chen[1]

[1]The EHF Key Laboratory of Science, School of Electronic Science and Engineering, University of Electronic Science and Technology of China, Chengdu, 611731, China and [2]The Shen Zhen Research Institute of Zhe Jiang University and Shen Zhen City Jiang Bo Chuang Xing Electronic Co. LD, Shen Zhen, 518000, China

Research Paper

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Author for correspondence:
Mou Luo, E-mail: 1969154557@qq.com

Abstract

A high-isolation diplexer based on a dual-mode substrate integrated waveguide (SIW) resonator is proposed in this paper. Based on the theory of the dual-mode resonator, the miniaturized diplexers are designed by using the SIW dual-mode resonators. The superior isolation of the diplexers is obtained because the two operating modes of the dual-mode SIW resonators are not directly coupled and there is no interference with each other. In order to further improve the isolation of the circuit, the number of the order of the diplexer is added. Equivalent circuits are given to analyze and design the dual-mode high-isolation diplexers. Detailed analyses are given according to the equivalent circuits. The dual-mode third-order and fourth-order diplexers are designed and fabricated. The measured results agree well with the simulated ones. The total sizes of the fabricated third-order and fourth-order diplexers are $1.78\lambda g \times 2.64\lambda g$ and $1.79\lambda g \times 3.63\lambda g$, respectively.

Introduction

At the background of the rapid development of the microwave communication systems, the demand for various high-performance passive or active circuits has increased greatly [1–23]. Among these different circuits, the diplexer, which is used to transfer signals of different frequency bands to different channels, shows its indispensable role in communication systems [1]. The traditional diplexer consists of two bandpass filters and a three-port matching network. In order to realize the miniaturization of the resonant unit, a variety of miniaturized structures have been proposed: step impedance resonator [2–4], dual-mode structure [5–14], and defective ground structure [15 16]. Because the dual-mode structure can reduce the number of the resonators and the overall size of the circuit, it is more widely used in microwave systems compared with other structures. Moreover, a dual-mode resonator based on the substrate integrated waveguide (SIW) structure has better frequency selection and lower insertion loss, making it a better choice for high-frequency circuit design [17–20].

What's more, another important component of the diplexer is the common part connecting the two channels. The traditional matching network takes the form of a T-shaped structure [21–23]. Though it can achieve high isolation and good impedance matching, it often takes up a lot of space [21–23]. So the design of common part in the form of a common resonator is introduced in order to miniaturize the circuit.

In this paper, a dual-mode diplexer with high isolation, compact size, and good out-of-band rejection is proposed. It is mainly designed by using the SIW dual-mode resonator. To get higher isolation of the diplexer, it is useful to increase the number of the order of the circuit. Finally, the presented dual-mode high-isolation diplexers are designed and fabricated. The total sizes of the fabricated third-order and fourth-order diplexers are $1.78\lambda g \times 2.64\lambda g$ and $1.79\lambda g \times 3.63\lambda g$, respectively.

Analysis and design

The structures of the presented dual-mode high-isolation diplexers have been shown in Fig. 1. The overall structures of the third-order and fourth-order circuits are shown in Figs 1(a) and 1(b), respectively. The structures of the circuits are based on the dual-mode SIW resonators, which have the advantages of high quality factor Q and low loss. It can be seen that the number of the required resonant cavities is reduced by half due to the use of dual-passband filters which are based on SIW dual-mode resonators. In addition, the common port of the diplexer is designed with a common resonant cavity structure, so the size of the circuit is more compact without the additional matching circuit.

In order to realize the coupling of the two working modes between the resonant cavities, a coupling structure as shown in Fig. 1 is adopted. The coupling strength is controlled by the size

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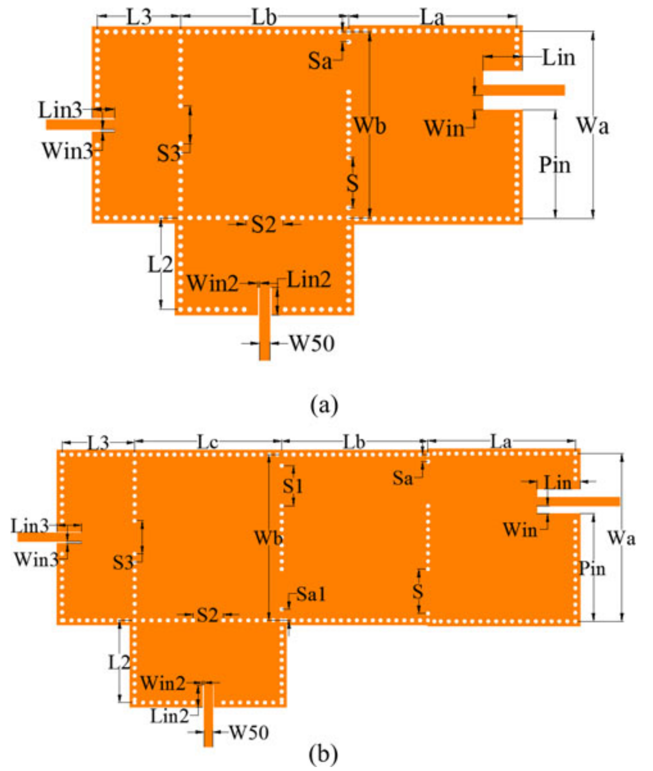

Fig. 1. Structures of the high-isolation diplexers. (a) Structure of the third-order diplexer and (b) structure of the fourth-order diplexer.

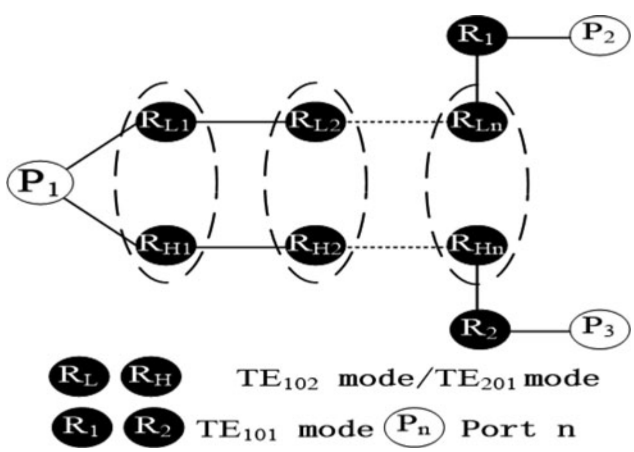

Fig. 2. The circuit topology of the multi-order diplexer.

of the coupling window S and the position of the coupling window Sa. The larger the coupling window, the stronger the coupling strength between the two resonators.

The circuit topology of the multi-order diplexer is shown in Fig. 2. R_L and R_H enclosed by dotted frames represent TE_{102} mode and TE_{201} mode of the dual-mode resonator respectively. Both R_1 and R_2 represent TE_{101} modes, which are the dominant modes of the single-mode resonators connected at the end of the multi-order diplexer. The dotted lines in Fig. 2 indicate that many dual-mode resonators can be inserted to achieve multi-stage cascade. The use of a dual-mode resonator as the common cavity not only eliminates redundant resonators, but also eliminates additional matching circuits, which is helpful to achieve the miniaturization of the circuit.

The resonant frequencies f_{102} and f_{201} of the SIW rectangular resonator in TE_{102} mode and TE_{201} mode can be obtained by the following equations:

$$f_{102} = \frac{c}{2\sqrt{\varepsilon_r \mu_r}} \sqrt{\left(\frac{1}{2L}\right)^2 + \left(\frac{1}{W}\right)^2} \quad (1)$$

$$f_{201} = \frac{c}{2\sqrt{\varepsilon_r \mu_r}} \sqrt{\left(\frac{1}{L}\right)^2 + \left(\frac{1}{2W}\right)^2} \quad (2)$$

Here, L and W are the length and width of the rectangular resonator, respectively.

Figure 3 shows the electric field distributions of the fourth-order diplexer. It can be seen that the electric field distributions of the two paths are orthogonal and there is no direct coupling with each other. Because the two operating modes are not directly coupled in this circuit, the mutual interference between the two passbands is small and there is superior isolation of the diplexer.

In order to further separate the two resonant frequencies of the dual-mode resonator at the output ports and improve the isolation between the output ports, two single-mode resonators are connected at the output ports, which are operating in the dominant mode TE_{101}.

In order to get superior isolation and better out-of-band rejection of the proposed diplexer, it is necessary to increase the number of the order of the circuit.

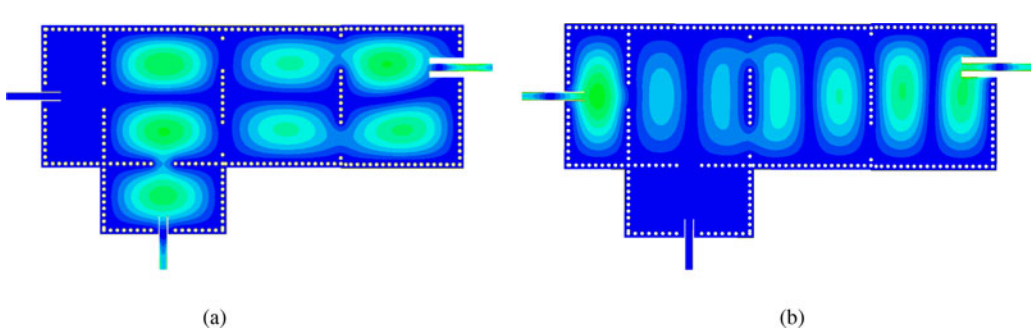

Fig. 3. Electric field distributions of the fourth-order diplexer. (a) Electric field distribution of the low-passband situation and (b) electric field distribution of the high-passband situation.

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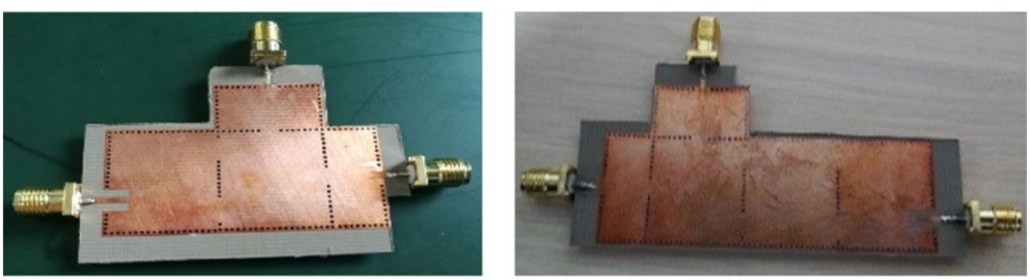
Table 1. The final physical sizes of the third-order diplexer (unit: mm)

Pin	Lin	Win	Wa	La	S	Sa	Wb
12.6	4.3	1.6	20.7	18.5	5.55	1.1	20.5
Lb	L2	S2	Win2	Lin2	S3	Win3	Lin3
18.5	10.1	4.08	0.2	3	4.18	0.2	2.5
L3	W50						
9.15	1.11						

Table 2. The final physical sizes of the fourth-order diplexer (unit: mm)

Pin	Lin	Win	Wa	La	S	Sa
13.6	5.4	1	21.2	18.6	5.6	0.9
Lb	Wb	S1	Sa1	Lc	Lc2	S2
18.5	21	5.1	1.4	18.55	10.4	3.85
Lin2	Win2	L3	S3	Lin3	Win3	W50
2.8	0.2	9.2	4.2	3.1	0.2	1.11



(a) (b)

Fig. 4. Physical photos of the diplexers. (a) Third-order diplexer and (b) fourth-order diplexer.

Implementation and measurements

Through the above analyses, the two high-isolation dual-mode diplexers are designed and fabricated with the substrate Taconic RF-35. The related parameters of this substrate are as follows: dielectric constant ε_r of 3.5, a thickness of 0.508 mm and a loss tangent of 0.0018. The structures are optimized in Ansys-HFSS. Table 1 shows the final physical sizes of the third-order diplexer circuit. The final physical sizes of the fourth-order diplexer are shown in Table 2. Figure 4 shows the fabricated dual-mode high-isolation diplexers. What's more, all the ports are connected by the type-SubMiniature version A connectors.

The simulated and measured results of the third-order diplexer are given in Fig. 5. The measured center frequencies of the passbands and 3 dB relative bandwidths are 8.9 GHz/2.8% and 9.42 GHz/3.5%, respectively. The measured return losses of the low passband and high passband are less than 18 and 20 dB, respectively, and the insertion losses of the two passbands are 4 and 3.1 dB, respectively. The measured isolation of the entire frequency band is better than 35 dB.

Figures 6(a) and 6(b) show the transmission, reflection, and isolation characteristics of the fourth-order diplexer. The measured center frequencies of the passbands and 3 dB relative bandwidths are 8.75 GHz/2.2% and 9.4 GHz/3.2%, respectively. The measured return losses of the low passband and high passband are less than 16.8 and 14 dB, respectively, and the insertion losses of the two passbands are 4.9 and 3.9 dB, respectively. The measured isolation of the entire frequency band is better than 42 dB. It can be seen that in the operating frequency band, the measured results agree well with the simulated ones, verifying the accuracy of the above design.

It can be seen from the simulated results that as the number of the order of the diplexer increases, the measured out-of-band rejection and isolation of the diplexer increase. However, as the number of the order of the diplexer increases, the size and the insertion loss of the circuit also increase. Therefore, it is necessary to make a trade-off based on the required performance when designing the circuit in practice. Table 3 shows the comparison with some prior diplexers. It can be seen that the proposed

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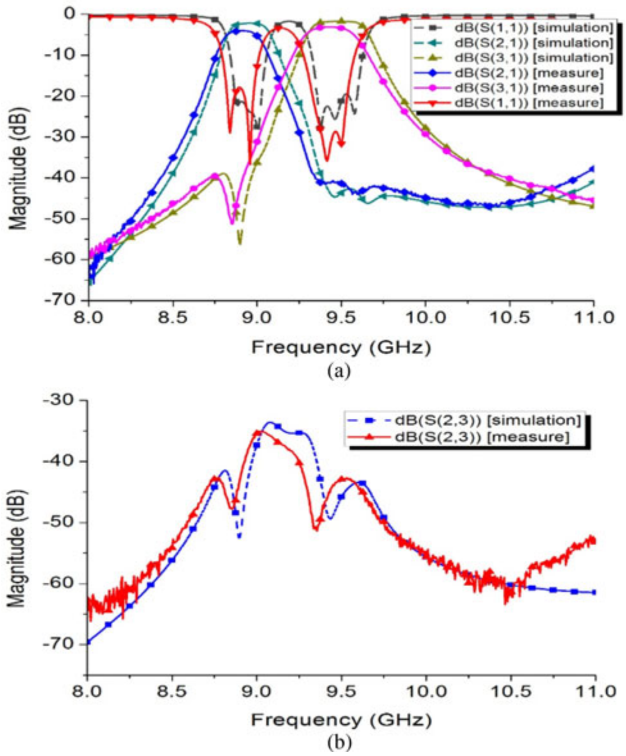

Fig. 5. Simulated and measured results of the fabricated third-order diplexer. (a) Transmission and reflection characteristics and (b) isolation.

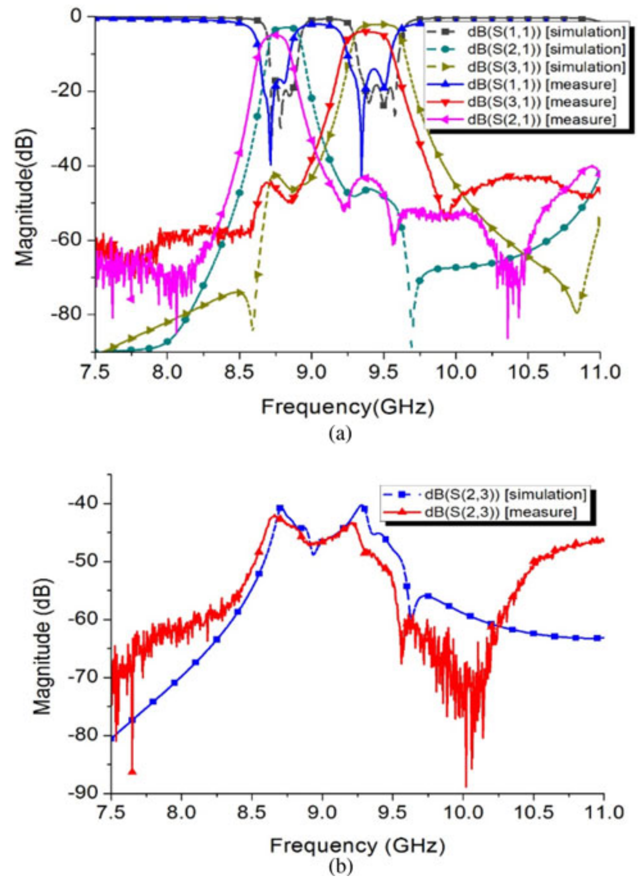

Fig. 6. Simulated and measured results of the fabricated fourth-order diplexer. (a) Transmission and reflection characteristics and (b) isolation.

Table 3. The comparison with some prior diplexers

Ref.	Return loss (dB)	Isolation (dB)	Freq. (GHz)	Insertion loss (dB)	Out-of-band rejection (dB)	Relative bandwidth (%)
[17]	>17/17	>20	9.7/10.3	<4/7	>29/28	1.1/2.4
[18]	>18/15	–	18.15/19	<3.05/2.3	>40/38	2.75/2.11
[20]	>12.9/13	>32	4.66/5.8	<1.6/2.3	>43/28	–
This work (third-order)	>18/20	>35	8.9/9.42	<4/3.1	>40/38	2.8/3.5
This work (fourth-order)	>16.8/14	>42	8.75/9.4	>4.9/3.9	>45/42	2.2/3.2

diplexers have the advantages of high isolation, excellent out-of-band rejection, and good impedance matching.

Conclusion

A high-isolation dual-mode diplexer based on the SIW structure has been presented. The dual-mode resonator structure has been used to reduce the size of the circuit. To analyze the proposed diplexers, the equivalent circuits have been used. The measured results of the dual-mode high-isolation diplexers agree well with the simulated ones. From the measured results, it can be seen that many advantages of the proposed diplexers can be summarized as follows: superior isolation, excellent impedance matching, and good out-of-band rejection.

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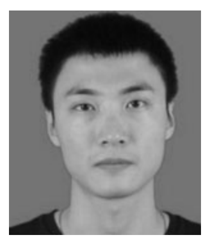
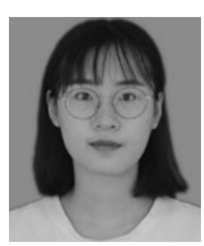
Kaijun Song (M'09-SM'12) received the M.S. degree in radio physics and the Ph.D. degree in electromagnetic field and microwave technology from the University of Electronic Science and Technology of China (UESTC), Chengdu, China, in 2005 and 2007, respectively. In 2011, he received the "New Century Excellent Talents in University Award" from Chinese Ministry of Education. He received the academic and technical leaders in Sichuan province in 2015. In 2019, he received the science and technology innovation talents in Sichuan province. Since 2007, he has been with the EHF Key Laboratory of Science, UESTC, where he is currently a full Professor. From 2007 to 2008, he was a postdoctoral research fellow with the Montana Tech of the University of Montana, Butte, USA, working on microwave/millimeter-wave circuits and microwave remote sensing technology. From 2008 to 2010, he was a research fellow with the State Key Laboratory of Millimeter Waves of China, Department of Electronic Engineering, City University of Hong Kong, on microwave/millimeter-wave power-combining technology and ultra-wideband (UWB) circuits. He was a senior visiting scholar with the State Key Laboratory of Millimeter Waves of China, Department of Electronic Engineering, City University of Hong Kong in November 2012. He has published more than 180 internationally refereed journal papers. His current research fields include microwave and millimeter-wave/THz power-combining technology; UWB circuits and technologies; microwave/millimeter-wave devices, circuits and systems; and microwave remote sensing technologies. Prof. Song is the Reviewer of tens of international journals, including IEEE Transactions and IEEE Letters.



Mou Luo was born in Sui Ning, Sichuan Province, China, in September 1996. He received the B.Sc. degree in Engineering from Southwest Jiaotong University, Chengdu, China, in 2018, and is currently working toward the Master's degree in electronic science and technology at University of Electronic Science and Technology of China. His research interests include microwave/millimeter-wave circuits and systems and Terahertz wave power-combining technologies.

Cuilin Zhong was born in Hengyang, Hunan, China. He received the M.Sc. degree and D.Sc. degree respectively in 2004 and 2009 with major at radio physics from the University of Electronic Science and Technology of China (UESTC), Chengdu, China. From August 2004 to November 2006, he worked on the RF technology research and development of wireless and mobile communication, and he is the team leader of the department of microwave circuit MCM in GUOREN communication company. His research interests include the microwave, antenna techniques, and radio technology of wireless communication and radar.



Yuxuan Chen was born in Nan Chang, Jiangxi Province, China, in April 1996. She received the B.Sc. degree in Engineering from Southwest University, Chongqing, China, in 2018, and is currently working toward the PhD degree in electronics and communication engineering at University of Electronic Science and Technology of China. Her research interests include microwave/millimeter-wave and Terahertz wave power-combining technologies.