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Dual-band filter design based on composite patch and substrate integrated waveguide structures

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Abstract: A new type of patch double band-pass filter based on circular substrate integrated waveguide is designed. By loading a circular metal patch, the circular SIW (circular substrate integrate waveguide, CSIW) cavity changes into the composite multilayer circular patch SIW filter. Compared to dual mode CSIW filter, composite multilayer circular patch SIW resonator not only reduces the resonant eigen mode frequency of its main mode, but also adds new modes to form a dual band. To prove its effectiveness, a simulation model is built in HFSS (high frequency structure simulator). Then through parameter optimization, the dual-band composite multilayer circular patch SIW filter is obtained. The results show that the dual-band frequency of the filter is from 1.88 GHz to 2.08 GHz and from 3.35 GHz to 3.60 GHz, and that the upper and lower sidebands of the two passbands have Transmission zeros, which shows good selectivity.

Key words: dual-band filter; magnetic wall; Composite Patches

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基于复合贴片 CSIW 结构的双带滤波器设计

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摘要：设计了一种基于圆形基片集成波导(circular substrate integrate waveguide, CSIW)的新型多层圆形贴片双频带通滤波器. 通过中间层加载圆形金属片，将 CSIW 谐振腔转变为复合多层圆形贴片谐振腔. 与 SIW 双模圆腔滤波器相比，降低了其主要工作模式的谐振频率，并且增加了新的圆形贴片谐振模式来形成双带. 为了验证其有效性，在 HFSS(high frequency structure simulator)中建立仿真模型. 在进行参数优化后，得到了双通带滤波器. 结果表明，该滤波器的双频范围为 1.88 GHz～2.08 GHz，3.35 GHz～3.60 GHz，在两个通带的上下边带均有零点，具有很好地选择性.

关键词：双频滤波器；磁壁；复合结构

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0 Introduction

SIW[1] was proposed by Prof. Wu for the first time by adding periodic metallic vias to guide wave which is similar to metal waveguide. Then Circular SIW (CSIW) filter structure[2-3] and half mode substrate integrated waveguide (HMSIW) filter were proposed[4]. The layout of the single-mode filter is still large. In the traditional SIW filter design, the cascade of the main mode is mainly used, so the design of the multi-mode SIW filter has gradually received attention.

Most multimode SIW filters or multimode patch filters are based on the research of dual degenerate mode filters in a CSIW resonator by introducing a metallized hole array in the center of a CSIW cavity, a three-mode filter is constructed using the main mode TM_{010} of the disturbed CSIW cavity and two degenerate modes TM_{110} of the first high mode[5]. For a better understanding of the control of each mode in a multi-mode patch filter, the dual-mode single-band resonator would be a good way. Perturbation on the symmetry plane of the cavity separates the degenerate mode pair, which is equivalent to two tuned circuits[6-7]. Therefore, the natural order of the filter is reduced by half, which reduces the size of the filter and makes the structure compact[8-9].

Recently, a research group proposed that the introduction of rectangular patches inside the rectangular SIW cavity can improve the performance of the SIW cavity filter[10]. With the filter designed using this structure, the frequency of the new working mode of the resonant cavity named composite multilayer circular patch SIW mode is greatly reduced with the introduction of the patch and with the filter remaining the same size, multi-mode dual-band result is achieved through perturbation.

CSIW structure has more degenerate modes in mode, so compared with rectangular cavity, it has more advantages in forming a narrow band passband. Thus, this paper proposes a miniaturized dual-broad-band filter by using the composite multilayer circular patch SIW.

1 Structure analysis of resonatorand filter

The nested structure used in this paper is shown in Fig. 1. The external cavity structure used is a circular cavity SIW resonator. A circular metal patch is embedded in the middle of the circular cavity SIW which divides the substrate into two parts: bottom and top.

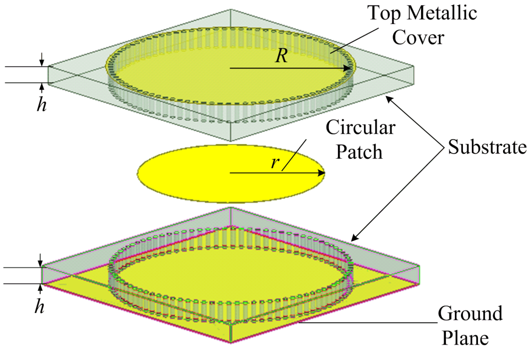


Fig. 1 3D structure of the composite multilayer circular patch SIW

The thickness of the upper and lower substrates is 0. 508 mm, and the thickness of the circular patch is 0. 101 mm whose radius r is 22. 5 mm. The radius of the metallic via is 0. 6 mm and the distance in between is 2 mm. And R which represents the radius of the circular SIW cavity is 30 mm.

According to classical theory, intrinsic mode frequencies of CSIW cavity resonator are shown in the following:

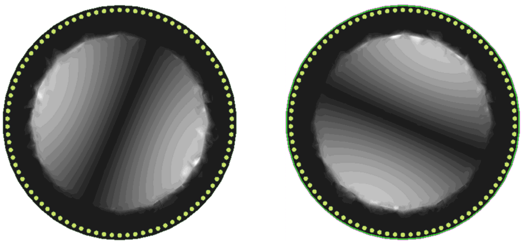
$$f_e = \frac{\mu_{mn} c}{2\pi r \sqrt{\varepsilon_r}} \tag{1}$$

where μ_{mn} is the nth zero point of the Bezier function of order m, $m = 0, 1, 2, \cdots$ $n = 1, 2 \cdots$, r is the equivalent radius of the SIW cavity, and ε_r is the dielectric constant of the substrate.

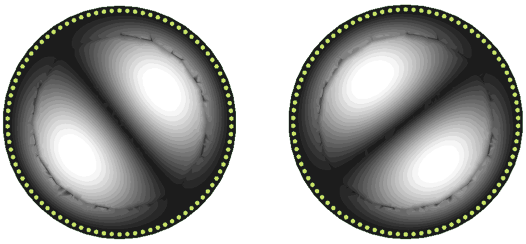
If the thickness of the circular patch is far less than its radius r, the resonant frequency of the resonant mode caused by the circular patch can be summarized as follows:

$$f_{nm0} = \frac{p'_{nm} c}{2\pi r \sqrt{\varepsilon_r}} \tag{2}$$

This paper uses the first pair of degenerate modes TM_{110} introduced via the composite multilayer circular patch SIW structure, as well as the first pair of degenerate modes TM_{110} of the CSIW resonant cavity. In the eigen mode simulation, the electric field distribution in the cavity is shown in Fig. 2.



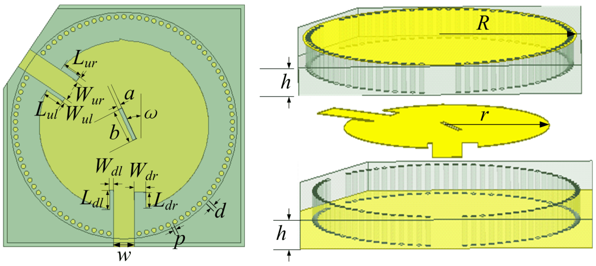
(a) TM_{110} mode 2.2 GHz (b) TM_{110} degenerate mode 2.2 GHz



(c) SIW cavity TM_{110} mode 3.2 GHz (d) SIW cavity TM_{110} degenerate mode 3.2 GHz

Fig. 2 circular patch modes

The filter design is shown in Fig. 3. The center frequencies of the two passbands are 2.9 GHz and 3.5GHz. The substrate is Rogers RO4350 which the dielectric constant is 3.66 and the thickness is 0.508 mm. The width of the feeder is $W=4.5$ mm.



(a) Top View (b) 3D View

Fig. 3 Geometry of the four-mode double-band filter

2 Performance analysis of Double band filter based on SIW Cavity

In order to stimulate two pairs of degenerate modes successfully, rectangular groove lines are etched in the center of circular metal patch. The size and position of groove lines play an important role in the formation of double passbands, which will be described in detail below.

Fig. 4 shows the S parameter change when the inclination ω of the small rectangular slot in the middle of the circular patch changes. It can be seen that the change of ω has little effect on the center frequency of the two passbands, but a great impact on the return loss in the first passband. With the increase of ω, the maximum return loss increases first and then decreases; the change of ω value has little effect on the position of the attenuation poles on the left and right sides of the two passbands. However, the position of the attenuation pole on the left side of the first pass band is shifted to the right side, so choosing the appropriate ω value is conducive to improving the filter′s outer band rejection ability.

Fig. 5 shows how the S parameters of the filter change when the width a of the small rectangular groove in the center of the circular patch changes. It can be seen from Fig. 5 that the change of a has a great influence on the return loss in the first passband, a little influence on the second passband, and the maximum return loss is better than -25 dB; the change of a has little influence on the insertion loss of the second passband, the attenuation poles on the left and right sides are almost unchanged, and the position of the attenuation poles on the left side of the first passband moves down with the increase of a. The center frequencies of the first and second bands of the filter are almost the same, and the bandwidth of the second pass band does not show much change.

Fig. 6 shows the S parameter when the length b of the small rectangular groove in the center of the circular patch changes. It can be seen from Fig. 6 that the change of b has a great impact on the performance of the filter. With the increase of b, the return loss in the first pass band of the filter is optimized, and the insertion loss of the first pass

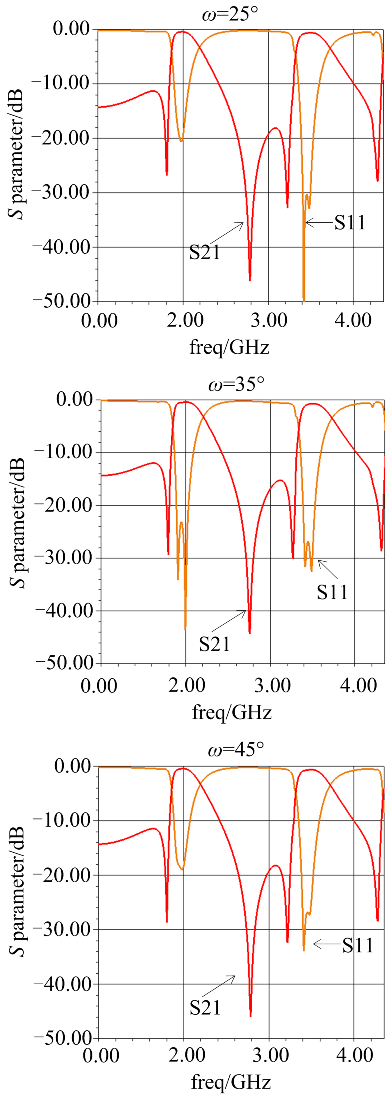


Fig. 4 Influence of tilt angleω on S parameter

band is also greatly affected. The increase of b causes the position of the attenuation pole on the left side of the first pass band to shift to the lower left, and the position of the attenuation pole on the right side is basically unchanged, so the filter passband bandwidth is widened; the insertion loss in the filter passband is also optimized with the incensement of b, the center frequency of the degenerate mode shifts to low frequency, but the insertion loss also increases. So it is very important to choose the appropriate b in the design of the filter.

Hence, a better filter can be designed by choosing appropriate parameters. The parameters selected in this paper are shown in Tab. 1.

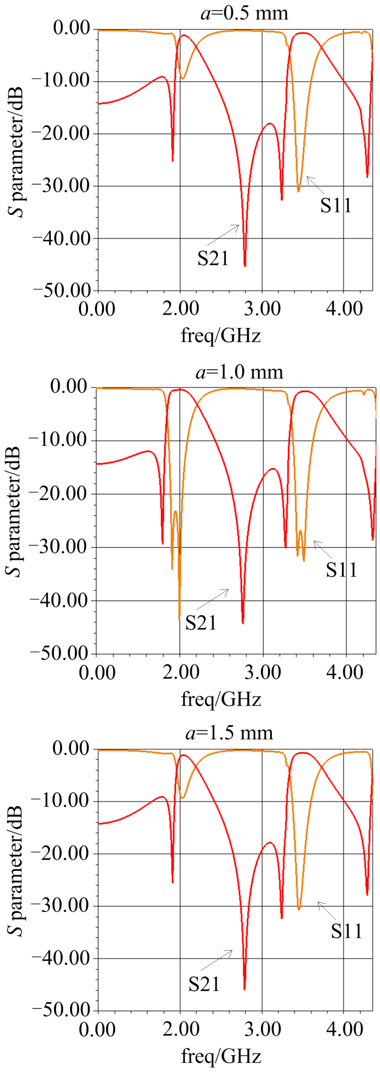


Fig. 5 Influence of width a on S parameter

Tab. 1 Parameter selection of this paper

ω	a	b	R	r	W	α
35°	1mm	9mm	30mm	22.5mm	4.5mm	146°

3 Simulation and measurement results

The simulated band-pass filter is fabricated and tested by Agilent E8363C vector network analyzer. The input and output ports are selected as 50 ohm SMA connector. The measurement scenario of the filter is shown in Fig. 7.

The measurement and simulation results are shown in Fig. 8.

From Fig. 8, in the measurement results, the 3 dB bandwidth of first band is arranged from 1.88GHz to 2.10GHz and the fractional bandwidth is

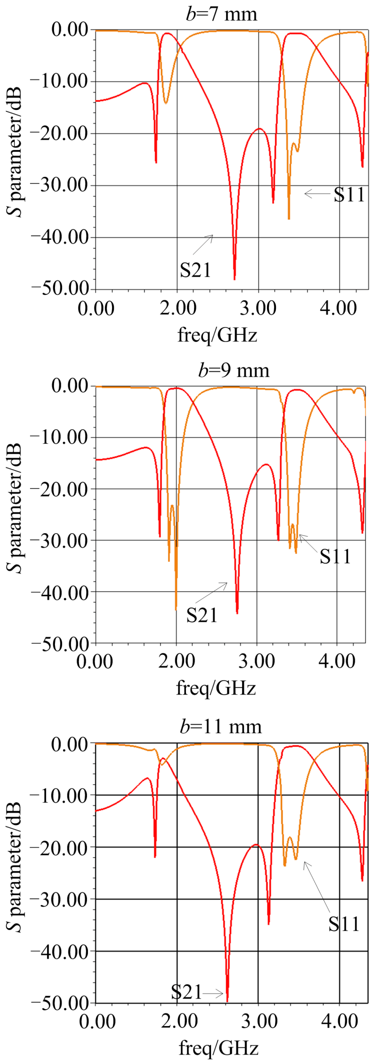


Fig. 6　Influence of length *b* on *S* parameter

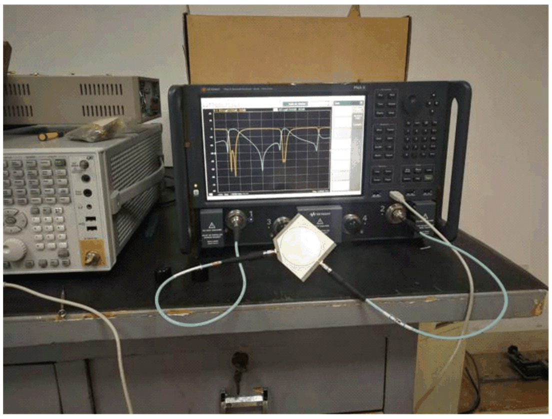


Fig. 7　Measurement photo of composite multilayer circular patch SIW filter

11.5%. In addition, the 3dB bandwidth of second band is from 3.21GHz to 3.40GHz and the fractional bandwidth is 5.75%. At this time, both bands are narrow bands and the value of return loss is greater than 1dB.

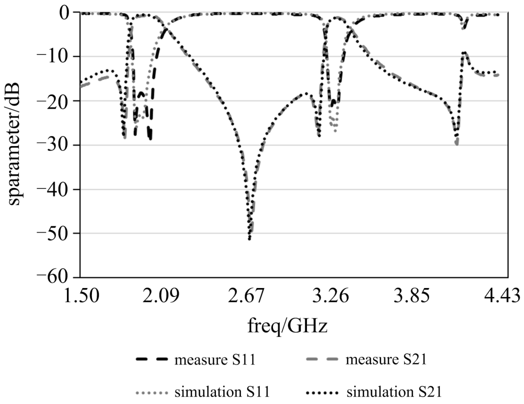


Fig. 8　Filter simulation and measure results

The design of double passband is realized, and the position of center frequency and zero point is basically consistent with the design requirements.

4　Conclusion

In this paper, we designed a circular patch double band-pass filter based on CSIW. We embedded the circular patch in the CSIW, and used HFSS simulation software for modeling and simulation. The simulation results show that the r can meet the dual-band requirements, and also have good out-of-band rejection in the band pass region. At the same time, the filter retained the advantages of SIW, such as low insertion loss, low cost, compact structure, etc., which can be widely used.

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