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A Novel Compact Wideband Bandpass Filter Using Rotational Symmetric Loaded Structure

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Abstract—A novel compact wideband bandpass filter using rotational symmetric loaded structure is proposed in this paper. A $\lambda/4$ parallel coupled line is first introduced to form a passband with desired center frequency. The rotational symmetric structure with short/open circuit stubs is then introduced as a loading structure to improve the filter's performance. The rotational symmetric loading structure is discussed in detail in this paper, and a pair of transmission zeros is obtained and located at two sides of the passband to improve the passband selectivity intensively. Moreover, three open circuit stubs are utilized to replace one single stub for obtaining a wide stopband. At last, the proposed filter is fabricated and measured, and the results show a good agreement with each other.

1. INTRODUCTION

The microwave filters find great applications as wireless communication technology is developed rapidly, and the microstrip filters with compact size and high selectivity as well as wide stopband are highly demanded. The resonator is an important part to constitute a microwave bandpass filter (BPF). Many different types of resonator have been proposed in recent years, typically multiple modes resonator (MMR) [1–4], and the MMR is commonly used due to several attractive features, such as compact size, additional modes for wide band or UWB operation, and wide upper stopband. Traditionally, $\lambda/4$ resonators and $\lambda/2$ resonators are used to constitute a wide-band bandpass filter [5–7], but the bulky size is a fatal disadvantage.

On the other hand, the wide stopband is another important part which needs to be considered when designing wideband bandpass filter. The EBG concept is introduced in [8], and the parasite resonant modes are fully rejected by the bandgap or bandstop behavior of the embedded EBG structure. The source-load coupling is an effective way to achieve a high selectivity and wide stopband as discussed in [9]. Recently, the rotational symmetric structure with coupling effect is proposed and discussed in [10–12]. The passband is obtained, and two TZs are also generated meanwhile.

In this paper, a $\lambda/4$ parallel coupled line is first used to form a passband, then a loaded rotational symmetric structure with open/short circuit stubs is proposed to achieve a quite good filter response. This is quite different from our previous work [10–12], and the coupling effect within the rotational symmetric structure is not concerned in our proposed structure. The rotational symmetric structure is seen as a novel open/short circuit with stubs loaded here and will be discussed in detail here. A pair of TZs is obtained and located at both sides of the passband to achieve a high selectivity as well as a wide stopband. Moreover, additional open circuit stubs are introduced to improve the upper stopband attenuation. Our novelty is the method of designing higher order wideband filter with compact size. Traditionally, the method of increasing bandpass filter resonating modes is cascading more resonators. Thus, it largely extends the overall length of filter structure. In our design, the length of filter remains unchanged with less than a quarter-wavelength with respected to center frequency of the filter when

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the number of filter's orders is increased. This provides an alternative method to design a compact higher-order wideband bandpass filter. Finally, the proposed filter is fabricated and measured at center frequency of 5 GHz, and the measured results are in good agreement with simulations.

2. LOADED ROTATIONAL SYMMETRIC STRUCTURE

$\lambda/4$ parallel coupled line is often used in input/output part to control a filter's quality factor or used between two coupled resonators to adjust the coupling coefficients among the resonators. In this paper, a single $\lambda/4$ parallel coupled line is utilized to form a passband with desired center frequency. The simulated results of a $\lambda/4$ parallel coupled line at $f_0 = 5$ GHz is shown in Fig. 1. The passband is generated but with quite poor filter performance.

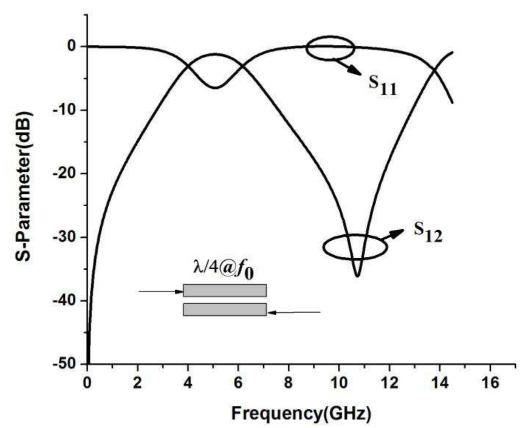


Figure 1. The simulated results of a $\lambda/4$ parallel coupled line at $f_0 = 5$ GHz.

In order to solve this problem, the first loaded rotational symmetric structure with two pairs of short-circuit stubs is proposed as shown in Fig. 2(a). The rotational symmetric means that the structure has no change after 180° rotation. The simulated results are given in Fig. 2(b) which indicates that another two TZs obtained and located out of the passband. The lower TZ (f_{Z1}) is generated by two pairs of stubs working together but dominantly controlled by shorter short circuit stubs as indicated in Fig. 2(c). The higher TZ (f_{Z2}) is generated not only through the two short circuit stubs but also by the parallel coupled line as indicated in Fig. 2(d). Moreover, the effect of shorter short circuit stubs is not dominant this time. The current distribution is directly obtained through the EM simulator (ADS momentum).

The stopband performance is improved intensively compared with the only parallel coupled line as shown in Fig. 1. The passband, however, needs to be optimized. Two open circuit stubs are introduced as shown in Fig. 3(a). One additional mode is gained to widen the passband. Moreover, f_{Z2} shifts to the lower frequency to obtain a high selectivity of the passband as shown in Fig. 3(b). The f_{Z1} changes a little because it is controlled by the shorter short circuit stubs dominantly. The compared results, also given in Fig. 3(b), indicate that a high selectivity is obtained as well as a good inband performance when rotational symmetric structure is introduced. Fig. 3(c) gives the change pattern of the inband modes when altering the length of open circuit stubs, and it is indicated that additional modes are obtained when further increasing the stub length. Fig. 3(d) depicts that f_{Z2} changes when altering the open circuit stub length while f_{Z1} stays the same.

Definitely, the positions of open/short circuit stubs will have a great effect on the TZs. Fig. 4(a) gives the change pattern of TZs when altering parameter S_3 as indicaed in Fig. 3(a). The two additional TZs move closer when decreasing S_3. Moreover, the attenuation of upper stopband changes when tuning this parameter. Fig. 4(b) gives the change trend of TZs when altering parameter S_5. The open circuit stub affects f_{z2} but has little effect on f_{z1}, and the attenuation of upper stopband also changes intensively when varying S_5.

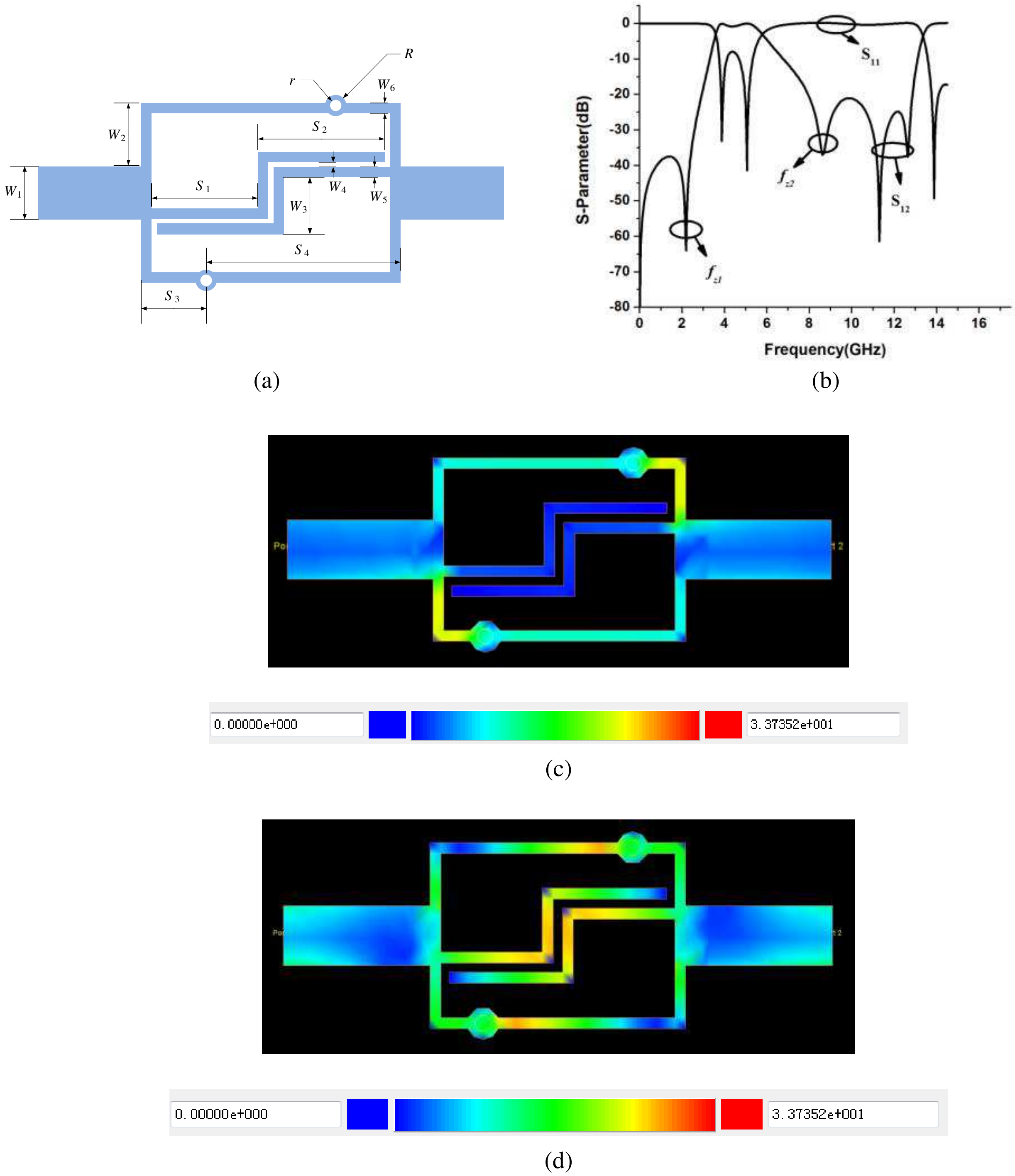


Figure 2. (a) The layout of first proposed loaded symmetric structure. (b) The simulated results of first proposed rotational symmetric loaded structure. (c) Current distribution at f_{z1} (2.32 GHz). (d) Current distribution at f_{z2} (8.56 GHz).

In order to achieve a wide stopband, another four stubs are introduced and shown in Fig. 5(a). The TZs are rarely affected when appending extra open circuit stubs while the stopband performance is improved as shown in Fig. 5(b). The attenuation of upper stopband is better than 20 dB ranging

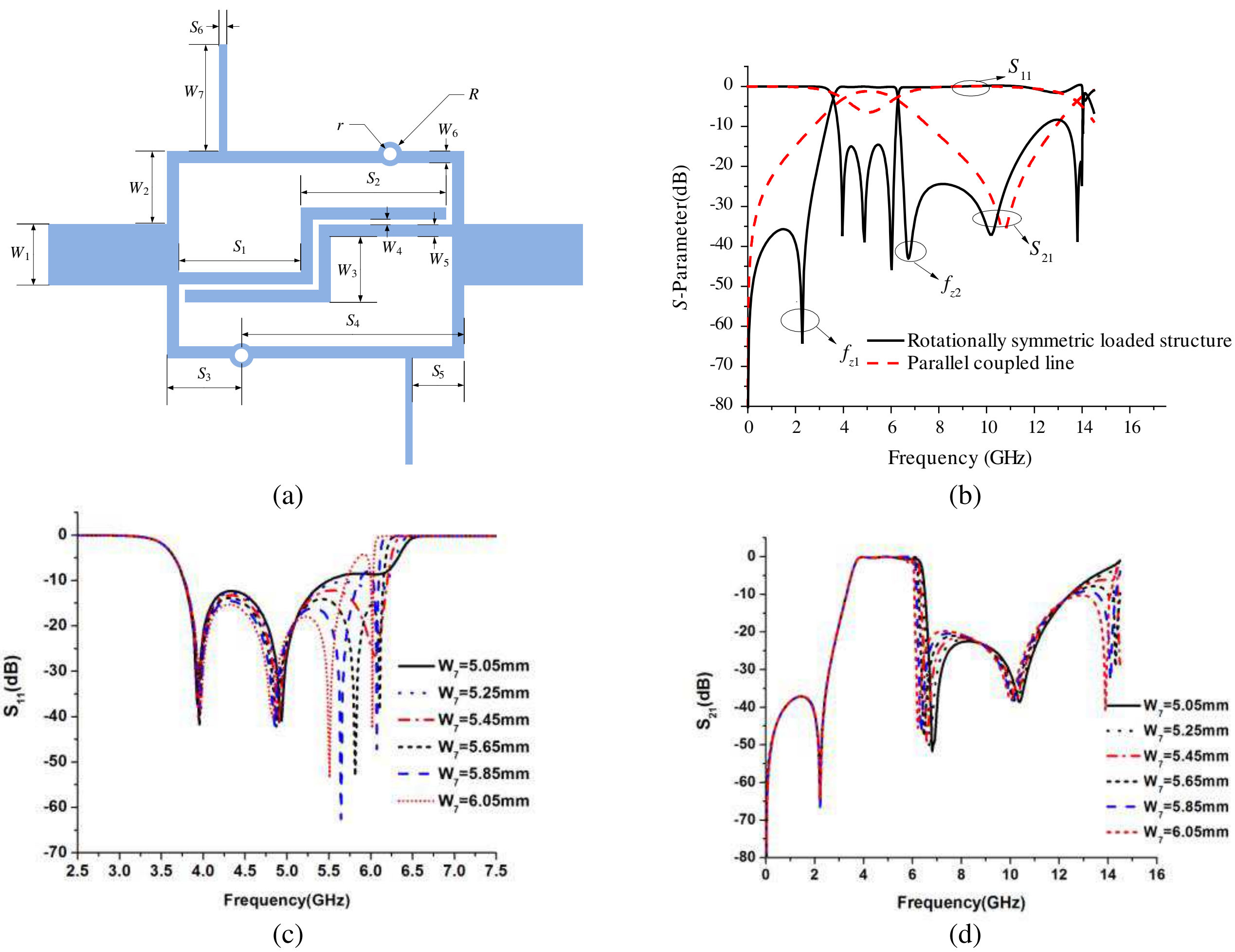


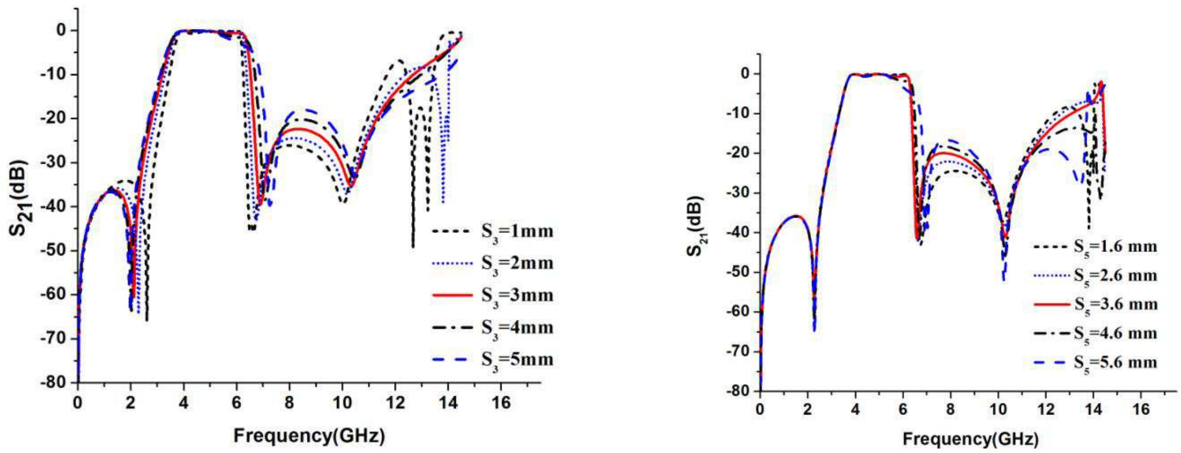
Figure 3. (a) The layout of $\lambda/4$ parallel coupled line filter loaded rotational symmetric structure. (b) The simulated results of the $\lambda/4$ parallel coupled line filter with/without loaded rotational symmetric structure. (c) The change pattern of inband modes when altering parameter W_7. (d) The change pattern of out-of-performance when altering parameter W_7.

from 6.4 GHz to 12.6 GHz from the simulated results, moreover, one additional mode obtained within the passband. Actually, the three open circuit stubs are equivalent to one capacitive loading or one transmission line as indicated in Fig. 3(c). Four modes are obtained when further increasing the stub length, while three stubs with shorter length also obtain the same response and compact size.

Table 1 provides the performance of our proposed wideband bandpass filter in comparison to those published ones, and it can demonstrate the advantages of our design, i.e., compact size, good stopband performance and high return loss.

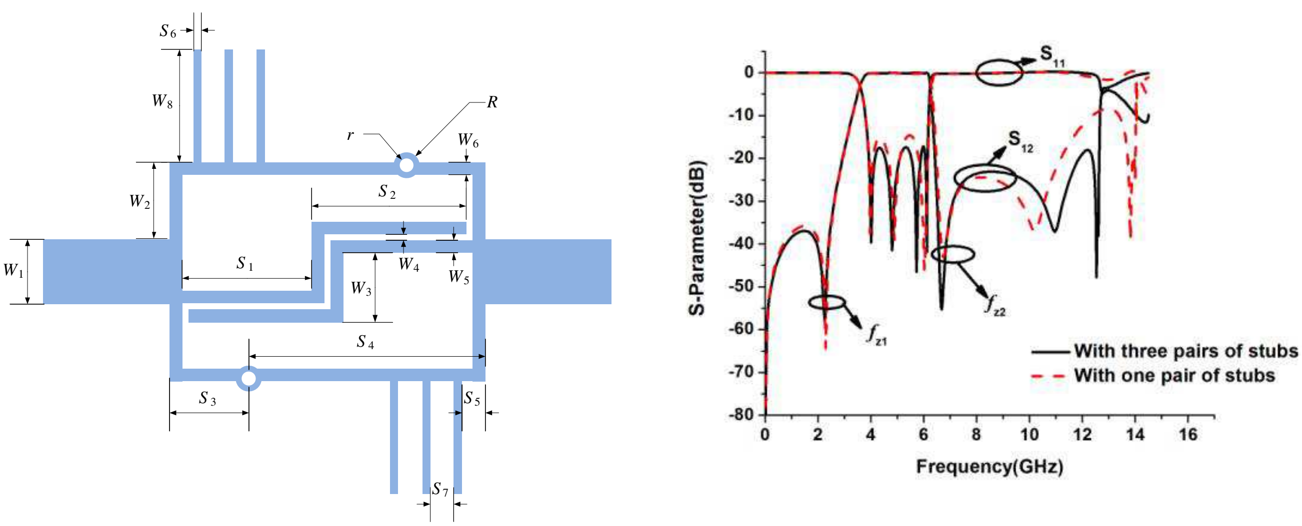
Table 1. Comparison of various wideband bandpass filters.

	Center Frequency	FBW	Size	Return Loss	Stopband
This work	5 GHz	42.8%	9.4 mm × 11.5 mm	> 17 dB	Good
[3]	3.98 GHz	69.2%	19.5 mm × 7.1 mm	> 16 dB	Poor
[4]	3 GHz	86.1%	7.2 mm × 13 mm	> 15 dB	Poor
[8]	6.5 GHz	105%	12.5 mm × 2 mm	> 11 dB	Good
[9]	3 GHz	48%	> 58.2 mm × 36 mm	> 12 dB	Good



(a) (b)

Figure 4. (a) The change pattern of the transmission zeros when altering parameter S_3. (b) The change pattern of the transmission zeros when altering parameter S_5.



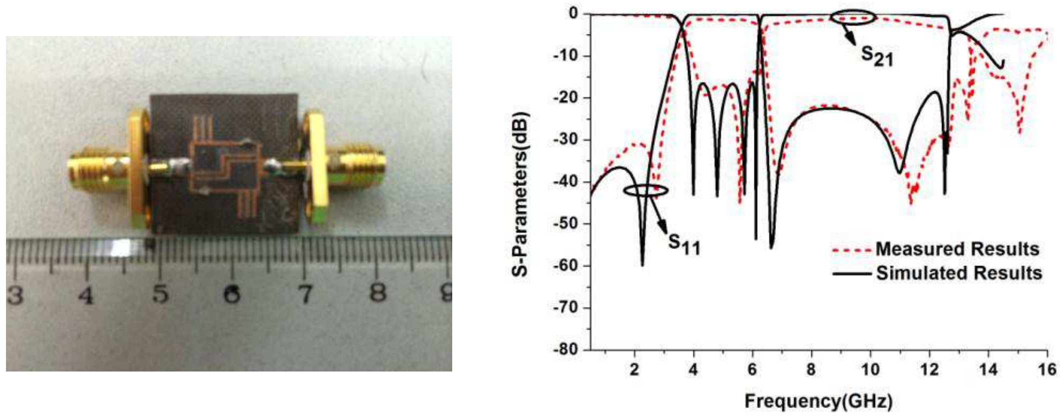
(a) (b)

Figure 5. (a) The layout of proposed structure with additional stubs. (b) The compared results between the proposed structure with one pair of stubs and with three pairs of stubs.

3. EXPERIMENTAL RESULTS

To verify the design, a proposed bandpass filter loaded rotational symmetric structure operated at 5 GHz is fabricated and measured. The substrate used herein has a dielectric constant of 2.55 and a thickness of 0.8 mm. The overall circuit sizes are $S_1 = 3.73$, $S_2 = 4.57$, $S_3 = 2.0$, $S_4 = 7.4$, $S_5 = 0.6$, $S_6 = 0.3$, $S_7 = 0.7$; $W_1 = 2.2$, $W_2 = 2.3$, $W_3 = 2.34$, $W_4 = 0.34$, $W_5 = 0.4$, $W_6 = 0.4$, $W_8 = 3.45$; $r = 0.3$, $R = 0.6$ (all in mm). Fig. 6(a) shows a photograph of the fabricated circuit. Fig. 6(b) gives a comparison between the simulated and the measured results.

The measured insertion loss is better than 1.26 dB in the passband, and the return loss is better than 14 dB. The measured 3 dB fractional bandwidth is about 42.8% ranging from 3.95 GHz to 6.1 GHz. Two extra TZs are obviously achieved. The lower stopband is better than 30 dB and the upper stopband



(a) (b)

Figure 6. (a) Photograph of the fabricated circuit; (b) Comparison between the measured results and simulated results.

better than 20 dB ranging from 6.4 GHz to 12.9 GHz. A good agreement is observed between the simulated and the measured results.

4. CONCLUSION

In this paper, a wideband bandpass filter with high selectivity and wide stopband is proposed. The initial filter is based on a $\lambda/4$ coupled line, then the proposed loaded rotational symmetric structure is introduced to achieve a pair of TZs which located at both sides of the passband. The TZs are generated by the two pairs of short circuit stubs and parallel coupled line. The open circuit stubs are used to relocate the higher TZ and to gain additional modes. Moreover, additional open circuit stubs are introduced to achieve a stopband with higher attenuation. At last, the proposed bandpass filter is fabricated and measured, and the measured and simulated results are in good agreement.

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