Miniaturized Microwave Filter Using Circular Spiral Resonators in a Single Metal Cavity

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***Abstract*—This paper proposes a novel miniaturized microwave filter based on circular spiral resonators (CSRs) embedded in a single metal cavity. The spiral structure is used to design filters in planar circuits with compact size, but not applied in cavity filters. The proposed CSR is firstly presented and analyzed, which has obvious size reduction compared to traditional cavity resonators, and still remain high filtering performance. Then, a second order filter using two CSRs sharing a metal cavity is designed, and it has two transmission zeroes (TZs) produced by the source-load coupling without additional coupling structure, which can improve the nearby stopband-rejection. The circuit size is 0.049λ_0 *0.026λ_0 *0.047λ_0. Finally, the proposed second order filter is fabricated and measured, the measured results are in good agreement with the simulated results.**

***Keywords*—circular spiral resonator (CSR), miniaturized size, metal cavity, source-load coupling, transmission zeroes (TZs).**

I. Introduction

Nowadays, the wireless communication system is an extremely important demand of the people's life. The improvement of social economy and living standards drive the continuous evolution of communication technology. Microwave filter, an important part of the communication system, is required to have miniaturized size, low power loss, high power capacity and high filtering performance. Planar transmission line are widely used to design filters with compact size [1]-[4]. The substrate integrated waveguide [5]-[6] has a higher unload quality factor than the traditional planar transmission line, and remain compact size, but it still have the drawback of poor power capacity. Cavity resonators, such as rectangular waveguide resonators [7]-[8], cylindrical waveguide resonators [9]-[10], coaxial cavity resonators [11]-[12], dielectric cavity resonators [13]-[14] have much higher unload quality factor, which can be used to design filter with low power loss, great power capacity and high filtering performance, and they are widely applied to the RF front circuits, but they have disadvantage in purpose of miniaturization design. For that, helical resonator in cavity is used to design cavity filters with miniaturized size [15]-[18]. The helical structure has an apparent advantage over the miniaturization design, it is about 90% size reduction compared to traditional cavity filters, and still remain high properties. However, it suffers from the design complexity.

In this paper, a novel miniaturized microwave filter using circular spiral resonator (CSR) in a single metal cavity is proposed. In section II, the novel CSR, composed by a metal

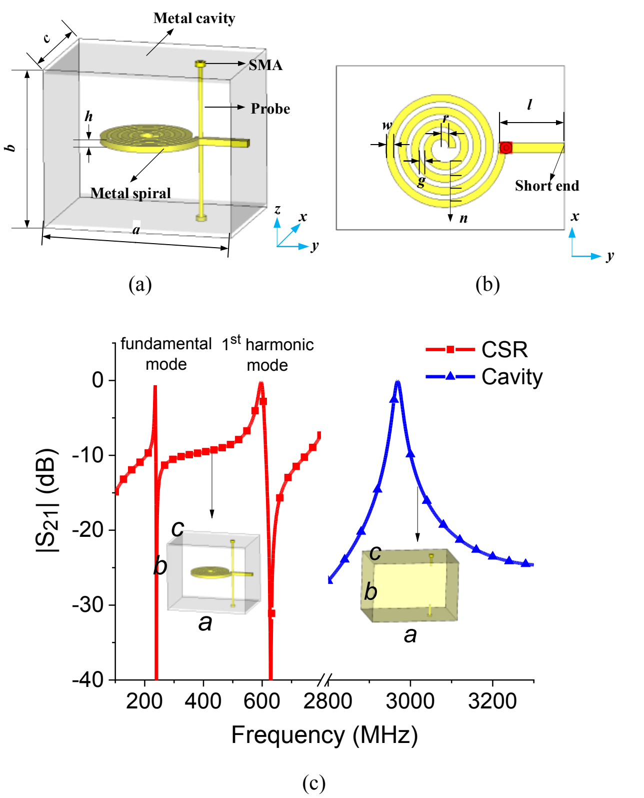


Fig. 1. (a) Three-dimensional view of the proposed spiral resonator. (b) Top view. (c) Resonant frequencies of the traditional cavity and proposed spiral resonator.

circular spiral, a short-end rectangular rod and a metal cavity, is firstly presented and analyzed in detail, the proposed resonator demonstrates an obvious miniaturization property compared to the traditional metal cavity and still remains high performance. Besides, it has lower design complexity compared to the helical resonator. Then, a second order is designed based on the proposed CSRs in section III, and it has two TZs produced by the source-load coupling. Finally, the proposed filter is fabricated and measured.

II. Analysis Of Circular Spiral Resonator In Cavity

Fig.1 (a) and (b) show the proposed circular spiral resonator (CSR) with marked dimensions, it includes a metal circular spiral, a metal rectangular rod and a metal cavity. The spiral is determined by the height (h), width (w), inner radius (r), gap (g) and the number (n) of turns. The initial dimensions are given as a=90, b=60, c=60, h=3, w=3, r=2, g=2.5 and n=4

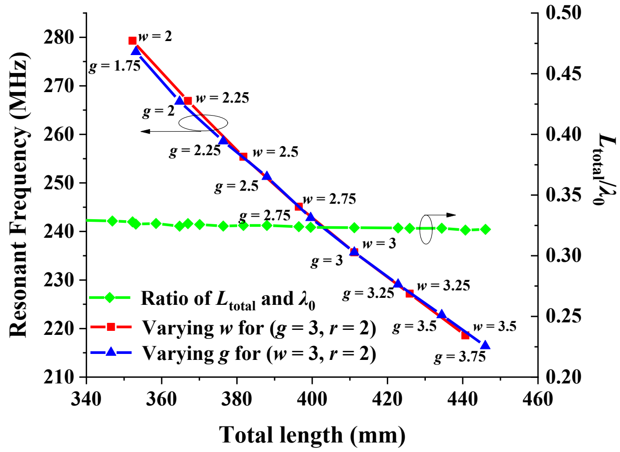


Fig. 2. Frequency tuning by w and g, ratio between L_{total} and λ_0.

(unit of all except n: mm). The rectangular rod is the part of proposed CSR, whose main role is to support CSR on the metallic cavity wall, and also contributes to the total length of the CSR. The SMA and the metal probe are combined to form the feeding structure and excite the mode. Fig.1 (c) shows the fundamental resonant frequencies of the traditional metal cavity and the proposed CSR under the condition of same cavity size, the former one is about 2970 MHz, while the latter one is about 250 MHz, the ratio between them is about 11.8 : 1, which implies that the proposed CSR has obvious advantage over the miniaturization design. Besides, it has a TZ produced by the source-load coupling and the first harmonic mode f_{p1} is about 2.56*f_0, which means that it has high selectivity and wide upper stopband-rejection.

Fig. 2 plots the resonant frequency tuning versus the total length L_{total} modified by g and w, while other parameters remain unchanged. It shows that the resonant frequency of the fundamental mode f_0 decreases when increasing the total length, which is similar to the planar transmission line. The total length of the resonator is about 0.32*λ_0 (wavelength at f_0), as shown in Fig. 2.

III. Filter Design Using Circular Spiral Resonator

After analyzing the proposed CSR, a second-order filter using two CSRs sharing a single metal cavity is presented, as shown in Fig. 3 (a) and (b). The filter is fed by the coaxial cable with an extended probe. The metal plane, which is placed at the middle of cavity along z-axis and connects to walls of the cavity along x-axis and y-axis, is used to control the coupling coefficient, as well as the distance D_2 between the two CSRs. The coupling mechanism is given in Fig.3 (c).The solid and dotted lines represent positive and negative coupling, respectively. The source-load coupling MSL is produced by the two probes with close distance, and the coupling between source and resonator 2 (or load and resonator 1) are similarly achieved. Then, a two-degree generalized Chebyshev filter with center frequency, namely f_0, 240 MHz, fractional bandwidth (FBW) 5% and return loss 20

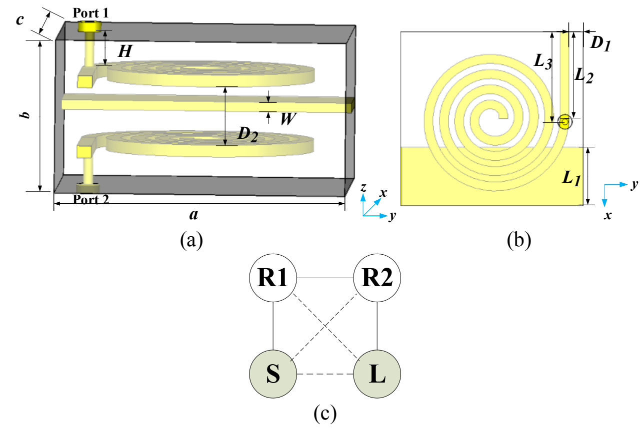


Fig. 3. (a) Three-dimensional view, (b) top view and (c) coupling mechanism of the second-order filter.

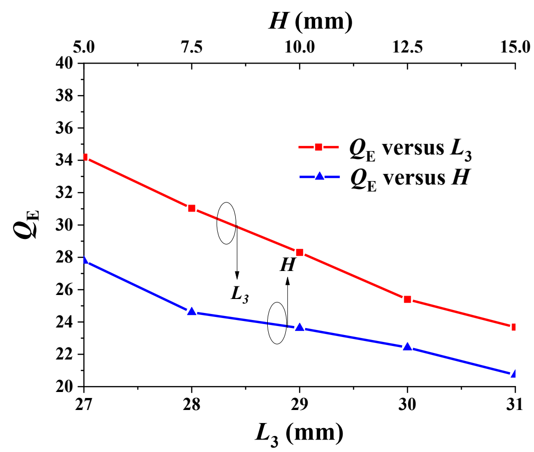


Fig. 4. Extraction of external Q-factor Q_E against L_3 and H.

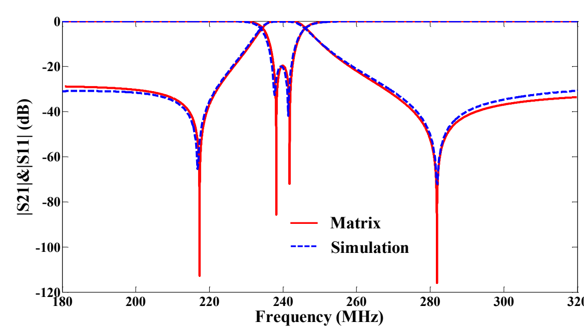


Fig. 5. Matrix response and simulated results.

dB with two TZs at 217 MHz and 282 MHz can be obtained by [19]-[21], and the normalized [(n+2) × (n+2)] coupling matrix M_1 of the filter is given in (1).

Then, the proposed filter is realized by implementing the normalized values in M_1 to the practical coupling values. The theoretical Q_e = 24.5 is obtained using equation (2) [21], and the extracted Q_E is obtained by equation (3) [22], where M_{S1} is the value in matrix M_1, f_{+90° and f_{-90° are the frequencies which have positive and negative 90-degree phase shift with respect to the phase of f_0. The extracted Q_E versus the parameters H and L_3 marked in Fig. 3 (a) is shown in Fig. 4, which covers the theoretical value 24.5. The matrix response and simulated results of the proposed second-order filter are shown in Fig. 5, the simulated results match very well to the theoretical response, the center frequency is 240 MHz with FBW 4.9%, insertion loss (IL) 0.32 dB and return loss (RL) 20 dB. Due to the existence of the unwanted diagonal cross-couplings M_{S2} and M_{L1} in matrix M_1, the response of M_1 is asymmetric [23]. The two TZs are generated by the source-load coupling, which can improve the nearby stopband-rejection.

$$M_1 = \begin{array}{c} \\ S \\ 1 \\ 2 \\ L \end{array} \begin{array}{c} \begin{matrix} S & \quad 1 & \quad 2 & \quad L \end{matrix} \\ \begin{bmatrix} 0 & 0.9051 & -0.0785 & -0.0169 \\ 0.9051 & 0 & 0.9228 & 0 \\ 0 & 0.9228 & 0 & 0.9051 \\ -0.0169 & -0.0785 & 0.9051 & 0 \end{bmatrix} \end{array} \quad (1)$$

$$Q_e = \frac{1}{FBW \cdot M_{S1}^2} \quad (2)$$

$$Q_E = \frac{f_0}{\Delta f_{\pm 90^\circ}} \quad (3)$$

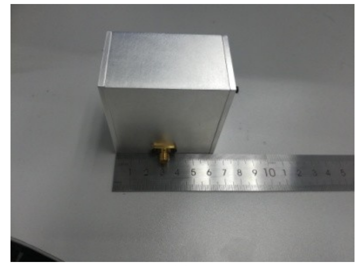
IV. Experimental Results

To prove the validity, the proposed second order filter is fabricated using brass material and the photographs is given in Fig. 6. The simulated and measured results are plotted in Fig. 7, the measured IL and RL are 0.4 dB and 18 dB, respectively, and the center frequency is 240 MHz, which match very well to the simulated results. While both the two TZs in measurement shifts to higher frequency than the simulation (about 5 MHz), the main reason is the discontinuity in the soldering between the probe and SMA, which has the influence on the source-load coupling, and results in the shift of the TZs.

The comparison with other reported filters is provided in Table 1, which indicates that the proposed filter has miniaturized circuit size, high filtering performance and low fabricated complexity.

Table 1. Comparison with other reported cavity filters

Ref.	Freq. (GHz)	Order	IL (dB)	Cavity Type	Size (λ_0*λ_0*λ_0)	Complexity	TZ
[8]	5.5	3	0.5	Rectangular Waveguide	0.81*0.73*0.44	Low	3
[13]	4.25	3	1.3	Dielectric Loaded	0.37*0.21*0.27	Low	3
[16]	0.244	2	0.18	Helical	0.055*0.043*0.054	High	1
[18]	0.43	2	2.1	Helical	0.055*0.032*0.042	High	0
This work	0.24	2	0.4	Spiral	0.049*0.026*0.047	Low	2



(a)

(b)

Fig. 6. Photograph of the proposed second-order filter: (a) Full view; (b) Inside view.

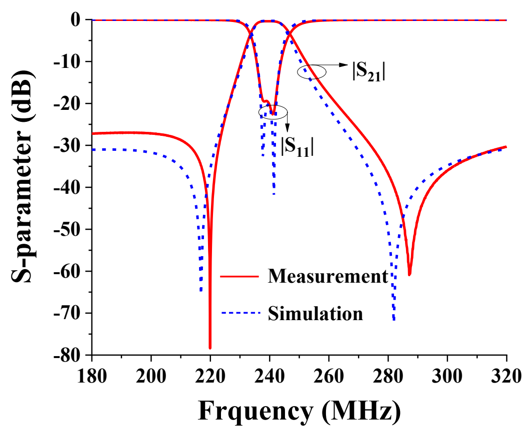


Fig. 7. Comparison of measured and simulated results.

V. Conclusion

A miniaturized microwave filter using circular spiral resonators (CSRs) in a single metal cavity is designed in this paper. The proposed CSR is firstly presented and analyzed, which obtains an obvious size reduction compared to the traditional metal cavity. Then, a second order BPF is designed using two CSRs in a single metal cavity. Two TZs produced by the source-load coupling is used to improve the nearby stopband rejection. The filter has miniaturized circuit size, high filtering performance and low fabricated complexity. Finally, the proposed BPF is fabricated and measured, the measured results have a good agreement with the simulated results.

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