A Novel Coupling Structure for Changing the Coupling Nature Between $TE_{01\delta}$-mode Dielectric Resonator and Combline Resonator

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Abstract **─** In this paper, a novel coupling structure is presented, which could easily change the coupling nature between combline resonator (CR) and dielectric resonator (DR). This coupling structure is based on electric field orientation of DR operating in $TE_{01\delta}$-mode, through altering the direction of copper sheet in the DR, the excited orientation of electric field would be changed along with the coupling nature between two resonators. To prove this method, two filters using cascaded triplet (CT) coupling relation are designed, fabricated and measured, showing the controllable coupling nature between CR and DR. Measured results confirmed the predicted performance.

Index Terms **─** Bandpass filter, combline resonator, coupling nature, dielectric resonator.

I. INTRODUCTION

With the rapid development of wireless communication, the frequency spectrum becomes more and more crowed. To utilize the frequency spectrum more efficiently, the bandpass filter in the wireless communication system should have steeper selectivity. Increasing the filter order is a conventional way to improve the selectivity of a bandpass filter, but deteriorate the insertion loss. A better way is introducing transmission zeros by cross-coupling. But, it will make a negative impact on the passband edge performance. Therefore, high Q resonator was employed to improve the passband performance in cross-coupling filters. In 2006, a novel approach to design bandpass filter based on resonators with non-uniform quality factors (Q) was firstly reported [1]. More flat passband can be achieved using this method. Then, this method was verified in [2] again, high Q and low Q path were connected in parallel to achieve good improvement of passband performance. In [3], a six-order series filter with non-uniform Q distribution was proposed to show how to select the most critical resonators which should be set high Q-factor in the series circuit. Compared with other filters consisting of resonators with uniform Q-factor, the application of the non-uniform Q with first and last resonators with lower Q-factor value than the rest of the cavities revealed that there is impact only in the absolute losses.

In practical engineering applications, due to the high Q value of dielectric resonator, the DR filters have good in-band performance. Many researches on DRs have been done so far [4-10]. However, spurious bands of DR filters are too closed to be accepted in practical applications. CR filters have good design flexibility, however, the employ of the cross-coupling will sacrifice the passband edge performance [11]. Therefore, in order to achieve steep selectivity and good in-band performance without sacrificing the dimension, CR and DR are both used to design a bandpass filter. Through circuit simulation, the most critical resonator in determining the passband edge performance could be found easily, which means in real model, this resonator should be high Q-factor so that the largest improvement of the passband edge insertion loss can be achieved. And a DR is always used here due to its high-Q characteristic [12]. In this way, the filter could have better out-band performance than dielectric filters and better passband edge performance than combline filters.

In [13], due to the coupling between the feeding probe and second DR cavity, the transmission zero was obtained, and rotating the angle of the feeding position, the transmission zero was shifted to the lower or upper stopband. In the previous designs, the coupling between CR and DR is achieved through the coupling channel which only coupling strength can be adjusted. Therefore, in this letter, a novel coupling structure is proposed to change the coupling nature between $TE_{01\delta}$-mode DR and CR. When the EM-field is coupling from CR to DR, through changing the rotating direction of the coupling structure in DR cavity, the coupling nature between two resonators would be changed. This is the first time that the coupling between CR and DR has been discussed.

II. COUPLING BETWEEN DR AND CR

Figure 1 shows the EM field distributions of a $TE_{01\delta}$-mode DR cavity and a CR cavity. The $TE_{01\delta}$-mode

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DR cavity has a loop electric field distribution and the magnetic field distributes alone the axis of the DR disk and at a sufficient distance outside the disk. The CR cavity has a radial electric field distribution outside the metal cylinder which surrounded by the magnetic field. Figure 2 demonstrates the proposed coupling structure. The coupling structure contains three parts, two copper cylinders and one copper sheet. The copper sheet is grounded at both ends (CSGE) by the copper cylinders, which could help fasten the copper sheet and make it stay at the strong EM field area.

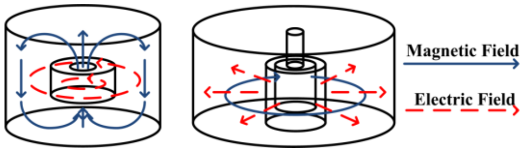


Fig. 1. EM field distributions of a $TE_{01\delta}$-mode DR cavity (left side) and a CR cavity (right side).

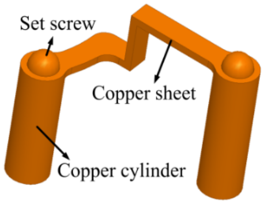
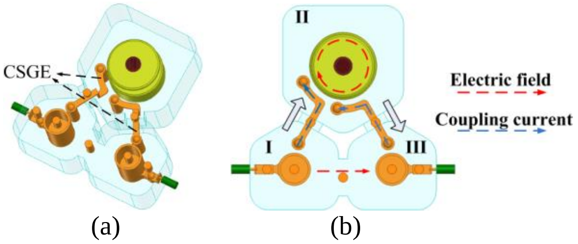


Fig. 2. The proposed coupling structure.

Figure 3 and Fig. 4 demonstrate the proposed model of the CT-based bandpass filter. Their input and output structures are constructed by CR while the main difference is the rotating direction of the coupling structure in cavity II. When a filter is working at its center frequency, according to the electromagnetic field theory shown below:

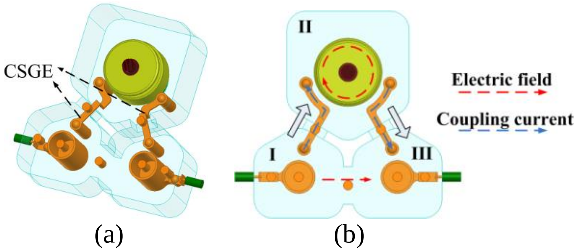
$$\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J} = \mu_0 \frac{\partial \vec{E}}{\partial t} + \vec{J}.$$

The coupling current and the electric field are in the same direction. As shown in Fig. 3 and Fig. 4, when electromagnetic field is coupling from cavity I (CR) to cavity II (DR), the radial electric field of the CR will lead to the coupling current flowing from cavity I to cavity II through the CSGE. Then the direction of the coupling current determines the clockwise rotating direction of the $TE_{01\delta}$-mode electric field in DR. Comparing Fig. 3 (b) with Fig. 4 (b), due to the different rotating direction of the CSGE between cavity II and cavity III, the induced coupling current had different flow directions. Therefore, the phase of the coupling current is changed by the type of the rotating direction, which results in different coupling nature between CR and DR.



(a) (b)

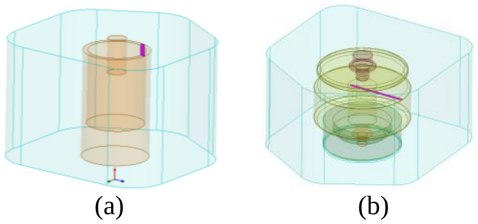
Fig. 3. The proposed CT-based bandpass filter with the same rotating direction of two CSGEs between DR and two CRs: (a) 3-D view and (b) top view.



(a) (b)

Fig. 4. The proposed CT-based bandpass filter with the opposite rotating direction of two CSGEs between DR and two CRs: (a) 3-D view and (b) top view.

The coupling coefficient between CR and DR is calculated by the Y-matrix method [14]. The EM-field is changed through changing the insertion depth of the tuning screws alone with the self- and mutual-coupling coefficient, which results in the controllable filter function. Figure 5 shows how to set the lumped port in CR and DR cavity when calculating the coupling coefficient between them. The port impedance should be studied before calculating the coupling strength. Figure 6 shows the computed coupling coefficients between CR and DR with different rotating angle θ of the CSGE in the DR cavity. The coupling coefficient increases along with the rotating angle θ of the CSGE in the DR cavity.



(a) (b)

Fig. 5. The way to set the lumped port in the CR and DR cavity when using the Y-matrix method: (a) CR cavity and (b) DR cavity.

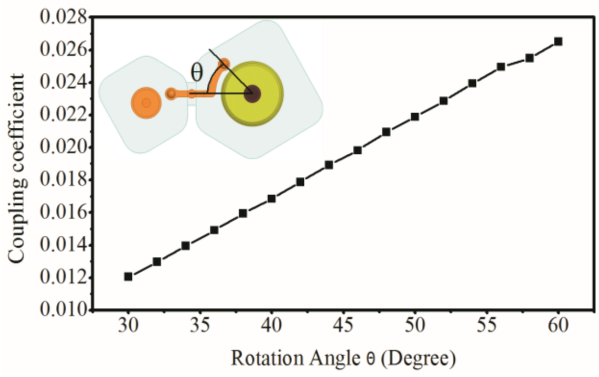


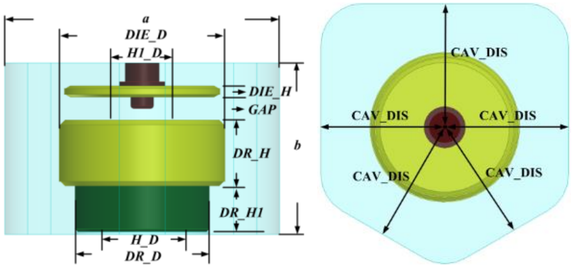
Fig. 6. Computed coupling coefficients between CR and DR when the CSGE rotating clockwise in DR from the top view.

III. FILTERS DESIGN

To verify the approach above, two CT-based bandpass filters [15] contain two CRs and one DR have been simulated, fabricated and measured. Two CRs were employed to build the input and output (I/O) structure of the two CT-based bandpass filter. The DR used in this design has a dielectric constant of 46. The details of the single DR cavity structure are shown in Fig. 7, where *DIE_D*=28.6 mm, *H1_D*=8.6 mm, *DIE_H*=2 mm, *DR_H*=11.5 mm, *DR_H1*=8 mm, *DR_D*=23.5 mm, *H_D*=17.5 mm. As shown in Fig. 7 (b), the cavity is pentagonal from the top view. The distance from the edge to the center point of the cavity is 26 mm (*CAV_DIS*), and the height is 30 mm. Besides, the details of the single CR cavity structure are shown in Fig. 8, where *CAV_a*=38 mm, *CAV_h*=25 mm, *COM_D1*=14 mm, *COM_D2*=12 mm, *COM_hin*=16 mm, *COM_hout*=22.5 mm. The cavity is also pentagonal from the top view. The distance from the edge to the center point of the cavity is 19 mm (*CAV_DIS*). The type of the tuning screw is M4.

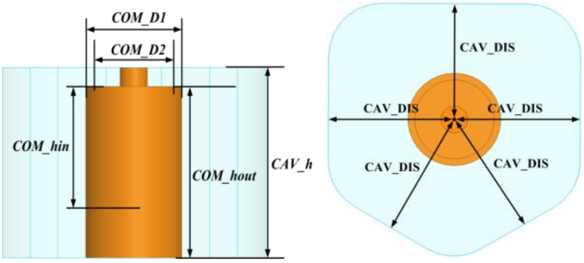
The coaxial connectors were associated with the first and last CR through two sheet metals. Two tuning screws were introduced to control the external quality factor Q_{ex} after fabrication. Figure 9 shows the computed external quality factor Q_{ex} of different screw insertion depths and various heights of the linked metal block.

Both of the proposed Chebyshev three-pole filters have a passband ripple of 0.0694 dB, a center frequency at 1.772 GHz and a bandwidth of 45 MHz. One of them has a transmission zero located at 1.68 GHz, thus the inter-resonator coupling value K_{12}=-K_{23}=0.024, K_{13}=0.0057, and external quality factor Q_{ex}=37.29 were required [16]. The other one had a transmission zero located at 1.84 GHz, which resulted in the inter-resonator coupling value K_{12}=K_{23}=0.023, K_{13}=0.0089, and the external quality factor Q_{ex}=37.28.



(a) (b)

Fig. 7. Single DR cavity with tuning dielectric disk: (a) side view and (b) top view.



(a) (b)

Fig. 8. Single CR cavity with tuning dielectric disk: (a) side view and (b) top view.

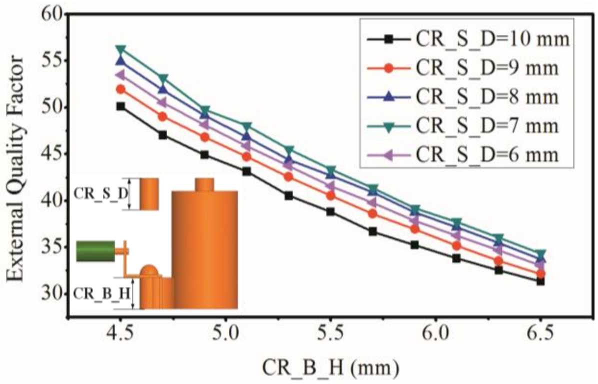


Fig. 9. Q_{ex} of different screw insertion depths as a function of the heights of the linked metal block.

The photographs of two fabricated three-pole bandpass filters are given in Fig. 10. The housings of two filters are constructed from aluminum. Figure 11 shows the E-M simulated and measured result of the proposed CT-based bandpass filters. In Fig. 11 (a), the two CSGEs in DR rotate in the same direction, which means that the coupling natures between two CRs and DR are the same. Therefore, the transmission zero (TZ1) appears at the upper stopband. However, in Fig. 11 (b), the rotating directions of two CSGEs in the DR are different. It means that the coupling natures between

DR and two CRs are different, which results in that the transmission zero (TZ1) appears at the lower stopband. Moreover, as shown in Fig. 11, the extra transmission zero appears at the upper stopband (TZ2) are caused by the CSGEs. The reason is that the CSGE serves as not only a coupling structure but also a half-wavelength resonator with two shorted ends.

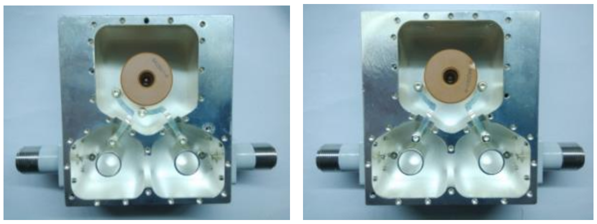
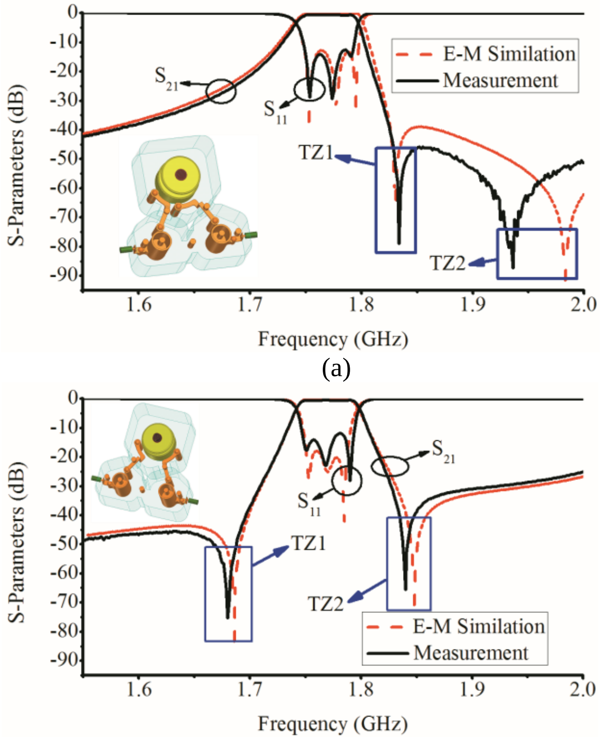

(a) (b)

Fig. 10. Photograph of two fabricated three-pole bandpass filter: (a) filter 1 and (b) filter 2.



(a)

(b)

Fig. 11. E-M Simulated and measured result of the proposed CT-based bandpass filter: (a) response of fabricated filter shown in Fig. 10 (a), and (b) response of fabricated filter shown in Fig. 10 (b).

IV. CONCLUSION

A novel structure to change the coupling nature between $TE_{01\delta}$-mode DR and CR was proposed in this letter. Different coupling nature between DR and CR has been achieved through altering the rotating direction of the coupling structure in $TE_{01\delta}$-mode DR. The coupling strength was enhanced due to the employ of the copper cylinders located at both sides of the copper sheet. Tuning screws were introduced to achieve the adjustability of the coupling coefficients. In order to verify the proposed method, two CT-based bandpass filters contain CR and DR were designed, fabricated and measured, respectively. The simulated and measured results prove the effectiveness of the proposed method.

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