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# INLINE $TE_{01\delta}$ MODE DIELECTRIC-RESONATOR FILTERS WITH CONTROLLABLE TRANSMISSION ZERO FOR WIRELESS BASE STATIONS

**Xiao Ouyang*** **and Bo-Yong Wang**

Communication Center, Guangzhou Power Supply Bureau, China Southern Power Grid Co., Ltd., 2 Tianhe Nan Er Rd., Tianhe District, Guangzhou, Guangdong 510620, China

**Abstract**—A method to control the transmission zero of $TE_{01\delta}$ mode dielectric-resonator (DR) filters for wireless base stations is proposed. Instead of using folder structures, dedicated coupling probes, or extra cavities, as required by conventional techniques, transmission zeros are realized. The feeding probes, extended along ring dielectric resonators, are used to excite the $TE_{01\delta}$ mode and introduce transmission zeros. By rotating the angle of feeding position, transmission zeros can be shifted to the lower or the upper stopband. Thus, $TE_{01\delta}$ mode dielectric resonator filters with quasi-elliptic responses are realized with only iris coupling components. Based on this method, fourth-order inline $TE_{01\delta}$ mode DR filters with different responses are designed and fabricated. Measured results confirm the predicted performance.

## 1. INTRODUCTION

The raid expansion of wireless communications has significantly increased the demands for high-performance microwave filters [1–3]. Due to the advantages of low loss, small size, and superior temperature stability, dielectric resonator filters are widely used in various communication systems [4–7]. To improve $TE_{01\delta}$ mode DR filters, cross-coupling is the most common way [8]. At least three more DRs must be utilized to realize transmission zeros, which are produced by cross-coupling. For size reduction, multi-mode dielectric resonators are utilized to design cross-coupling DR filters [9–11]. Dual-mode resonators allow for the realization of compact inline structures

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* Corresponding author: Xiao Ouyang (oyx.scut@gmail.com).

and have been extensively used for satellite applications to halve the number of physical cavities of a filter structure [12, 13]. Pseudo-elliptic responses can be easily obtained by realizing direct- and cross-coupling among the modes of adjacent resonators. However the cross-coupling, using folded structures, dedicated couplings, or extra cavities, will make the design procedures complex. A configuration of $TE_{01\delta}$ single-mode filter having inline structure and pseudo-elliptic response has been recently introduced in [14]. Changing the orientation of selected dielectric resonators can alter the coupling mode between resonators. Sequential coupling between adjacent resonators and cross coupling between non-adjacent resonators are controlled by metallic rods and waveguide steps. Using multiple methods to control the cross- and direct-coupling will increase the complexity of design procedures.

In this paper, we present an inline configuration for $TE_{01\delta}$ mode dielectric resonator filters characterized by simple and compact structures and improved performance. By changing the angles of the feeding positions, transmission zeros can be selected in the upper or lower stopband. Transmission zeros can be generated in inline $TE_{01\delta}$ mode dielectric resonator filters by cross-coupling starting from source or load. Thus, quasi-elliptic responses can be realized in $TE_{01\delta}$ mode DR cavities filters. Compared to the conventional cross-coupling $TE_{01\delta}$ mode DR filters, the proposed $TE_{01\delta}$ mode DR filters have simple design procedures and high selectivity. By using this method, we design and fabricate fourth-order $TE_{01\delta}$ mode DR filters with symmetric, asymmetric and without transmission zeros responses. All designed filters are realized by coupling iris, which can depend on engineering needs. The measured results are identical with the simulated results, which demonstrate the validity of the proposed method.

## 2. TRANSMISSION ZERO REALIZED IN $TE_{01\delta}$ MODE DR FILTERS

The electric and magnetic field distributions of $TE_{01\delta}$ mode dielectric resonator are illustrated in Figure 1. The $TE_{01\delta}$ mode dielectric resonator cavity has a circular electric field distribution, as well as a circular electric current distribution. The magnetic field is strongest on the axis of the dielectric resonator disk and at sufficient distance outside the disk. The field resembles that of an axial magnetic dipole. $TE_{01\delta}$ mode dielectric resonator cavity filters are commonly excited by probe feeding structures.

On the iris between DR cavities, the direction of the magnetic field vertically points upward or downward. So the problem of the first cavity can be treated in such a way that the second cavity is replaced

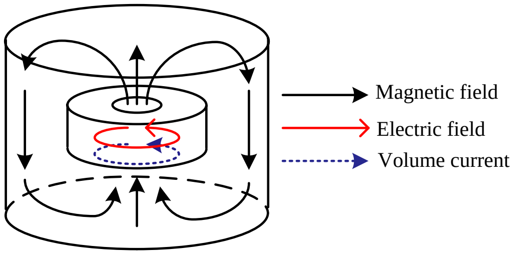


**Figure 1.** The field distributions of a $TE_{01\delta}$ mode dielectric resonator cavity.

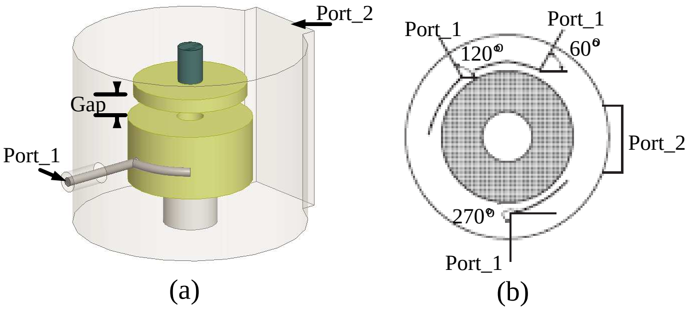


**Figure 2.** (a) A single $TE_{01\delta}$ mode dielectric resonator cavity excited by a probe and a wave-port. (b) Overlook of the single $TE_{01\delta}$ mode dielectric resonator cavity excited by a probe and a wave-port.

by a wave-port, as shown in Figure 2(a). In doing so, the problem will be simplified. A planar view of Figure 2(a) is shown in Figure 2(b), where $\theta$ is the angle of feeding position of the probe.

Figure 3 shows the E-M simulated responses of the structure shown in Figure 2 with different angles $\theta$ of feeding positions. The E-M simulation in this paper is carried out by HFSS. It is seen that there is a transmission zero $f_z$ near the $TE_{01\delta}$ mode resonance. The transmission zero variation rules are as follows:

1. When $\theta < 180°$, the transmission zero is located at the left side of the resonance and shifts leftward with the increase of $\theta$.
2. When $\theta > 180°$, the transmission zero is located at the right side of the resonance and also shifts leftward with the increase of $\theta$.
3. When $\theta = 180°$, there is no transmission zero existed.

The mode operation occurring for a feeding angle of 270° can be described by EM simulation of the electric field distribution shown in

Figure 4(a). The input or output excites the resonant $TE_{01\delta}$ mode at the first and last resonators, respectively. The iris is coupled to the probe by means of the evanescent $TE_{10}$ mode. When the feeding angle is changed to 180°, the direction of electric field would be changed to orthogonal orientation at iris, as shown in Figure 4(b). Because there is no horizontal part of electric field through the iris, it is hard to excite non-adjacent dielectric resonator for a feeding angle of 180°. Thus, the transmission zero would vanish under such condition. In high-order $TE_{01\delta}$ DR filters, the shifted transmission zeros are changed by the coupling from source/load to the non-adjacent resonator, which is a good realization of Macchirarella's theory [15]. Figure 5 summarizes the positions of transmission zeros with different angles $\theta$ of feeding

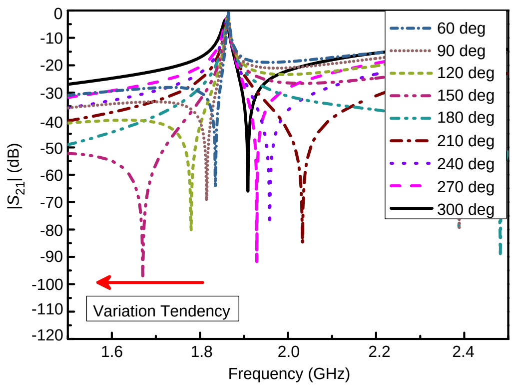


**Figure 3.** E-M simulated responses of the structure in Figure 2 with different angles of feeding position.

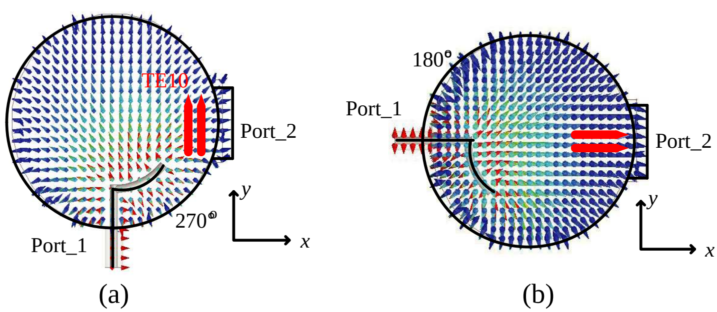


**Figure 4.** (a) The electric field distribution for a feeding angle of 270 degree. (b) The electric field distribution for a feeding angle of 180 degree.

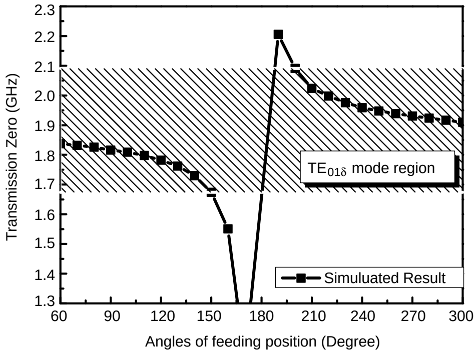


**Figure 5.** Variation of transmission zero $f_z$ versus angles of feeding position.

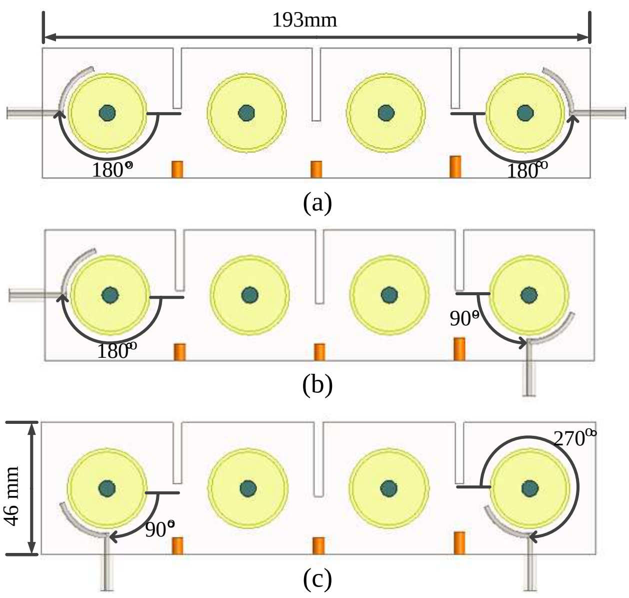


**Figure 6.** Top view of three four-pole dielectric resonator filter configurations.

position. The shadowed zone means the field distributions of dielectric resonator are still the $TE_{01\delta}$ mode. It is possible to achieve the transmission zero in the range 1.7 to 2.1 GHz for a center frequency of approximately 1.864 GHz.

## 3. THREE CONFIGURATIONS OF FOUR-POLE BANDPASS FILTER

From the above analysis we can know that, the control of the angles of feeding position can shift the transmission zeros. In the following, design examples are presented using the proposed filter configuration. Figure 6 presents three possible dielectric resonator filter configurations. The resulting filter topology, commonly referred to as triplet, is diagrammed in Figure 7.

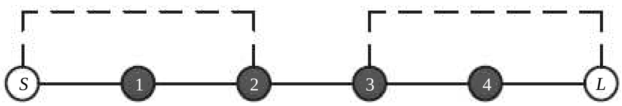


**Figure 7.** Topology of the source and load multi-resonator couplings inline configuration filters.

### 3.1. Filter without Transmission Zero

In the first example, the filter configuration in Figure 6(a) is used to realize a four-pole filter without transmission zero. To design a filter that has a center frequency 1.84 GHz, 0.5-dB insertion loss bandwidth 21 MHz. The input and output feeding angle are 180 degree, so that the coupling from source (or the load) to the second resonator does not exist. Thus, no transmission zero exists near the passband.

### 3.2. Filter with Asymmetric Transmission Zeros

The next filter example has the same center frequency and bandwidth. The angle of output feeding position is rotated to 90 degree. So a negative coupling for a triplet section had been realized with inline configuration. The triplet section starting from load to the last two resonators introduced a transmission zero near the passband.

### 3.3. Filter with Symmetric Transmission Zeros

In the last example, the filter configuration in Figure 6(c) is used to realize a four-pole filter with two transmission zeros near its passband. In configuration (c), the input (left) angle of feeding position is 90 degree while the output angle of feeding position is 270 degree. The negative coupling from the input to the first two resonators generates a transmission zero below its passband. Meanwhile, the positive coupling

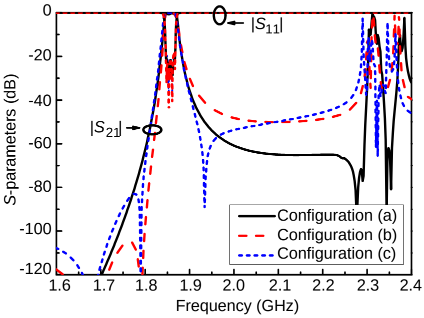


**Figure 8.** Simulated results of three four-pole dielectric resonator filter configurations.

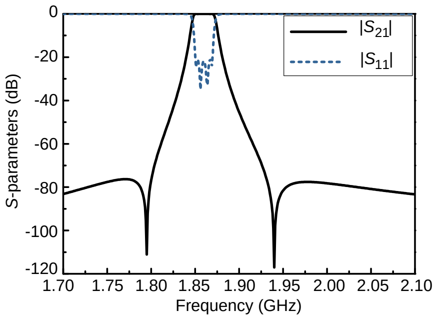


**Figure 9.** Coupling matrix response of the designed filter.

from the output to the last two resonators creates a transmission zero above its passband.

Three corresponding responses are shown in Figure 8.

## 4. FILTER DESIGN EXAMPLES

A four-pole $TE_{01\delta}$ mode DR filters with a passband ripple of 0.036 dB, a center frequency at 1.86 GHz, and a bandwidth of 20 MHz, and two stopband transmission zeros located at 1.785 and 1.93 GHz is designed.

According to the topology of Figure 7, the filtering function is described by the following normalized coupling matrix.

$$M = \begin{bmatrix} 0 & 1.061538 & -0.1481 & 0 & 0 & 0 \\ 1.061538 & 0.193812 & 0.93 & 0 & 0 & 0 \\ -0.1481 & 0.93 & -0.12374 & 0.7254 & 0 & 0 \\ 0 & 0 & 0.7254 & 0.117601 & 0.93 & 0.13424 \\ 0 & 0 & 0 & 0.93 & -0.16184 & 1.061538 \\ 0 & 0 & 0 & 0.13424 & 1.06538 & 0 \end{bmatrix}$$

The coupling matrix response is shown in Figure 9.

The HFSS simulated and measured results are shown in Figure 10, along with the coupling matrix response: the agreement between the curves validates the filter topology used to describe the structure. As shown in Figure 11, the filter has a 0.5 dB insertion loss bandwidth from 1.825 GHz to 1.846 GHz. Transmission zeros, created by input and output cavities, are at 1.785 and 1.93 GHz. The fluctuation of the in-band group delay is less than 8.6 ns. Figure 12 illustrates the properties of the input and output cavities, which effectively proves that they create two transmission zeros for this filter.

To demonstrate that the transmission zeros of the fabricated filter are tunable, we alternate the angle of output feeding position. The filtering function is described by the following coupling matric.

$$M=\begin{bmatrix} 0 & 1.061538 & -0.10439 & 0 & 0 & 0 \\ 1.061538 & 0.106169 & 0.93 & 0 & 0 & 0 \\ -0.10439 & 0.93 & -0.1478 & 0.7161 & 0 & 0 \\ 0 & 0 & 0.7161 & -0.14787 & 0.93 & -0.08691 \\ 0 & 0 & 0 & 0.93 & 0.106169 & 1.061538 \\ 0 & 0 & 0 & -0.08691 & 1.061538 & 0 \end{bmatrix}$$

The coupling matrix response is shown in Figure 13. Because of two transmission zeros at 1.755 and 1.77 GHz, a much higher rejection level of the lower stopband can be obtained, as shown in Figure 14.

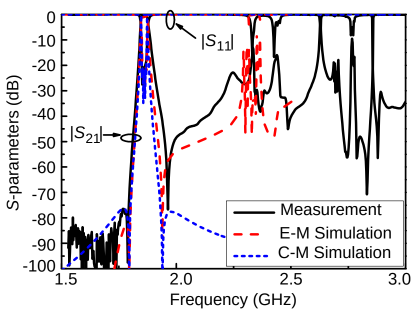


**Figure 10.** Measurement of the proposed dielectric resonator filter.

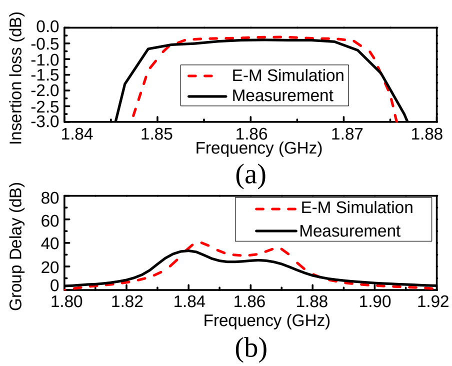


**Figure 11.** Measurement of the proposed DR filter. (a) Passband insertion losses. (b) Group delay.

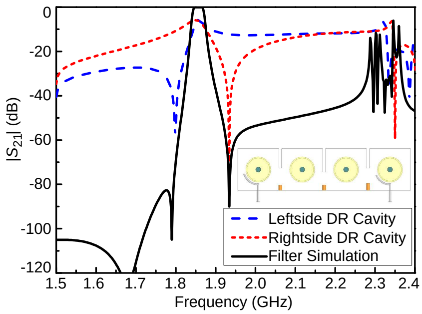


**Figure 12.** Contributions of the input and output cavities.

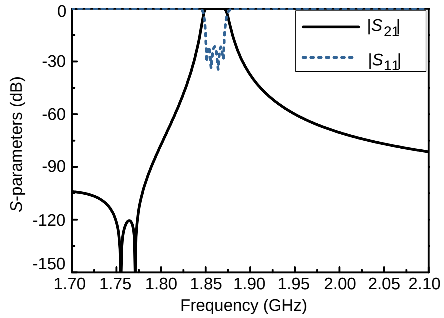


**Figure 13.** Coupling matrix response of the designed filter.

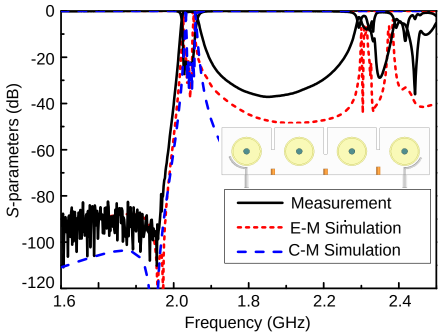


**Figure 14.** The input and output create two same transmission zeros at the lower stopband.

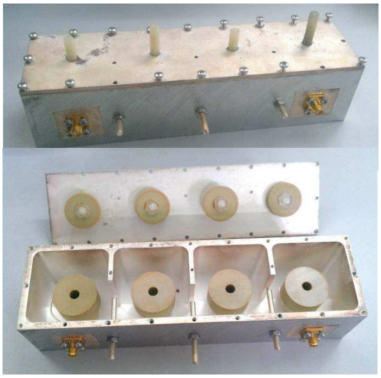

**Figure 15.** Photographs of manufactured four-pole DR filter.

The photographs of the designed and fabricated fourth-order $TE_{01\delta}$ mode DR filters are given in Figure 15.

## 5. CONCLUSION

A method to design controllable transmission zeros in inline $TE_{01\delta}$ mode DR filter was proposed. Firstly, the transmission zero in inline DR cavity filter has been analyzed. Rotating the angle of feeding position, transmission zero can be shifted to the lower or the upper stopband. Based on this method, quasi-elliptic $TE_{01\delta}$ mode DR filters are realized by only iris coupling components. Fourth-order $TE_{01\delta}$ mode DR filters with asymmetric, symmetric and without transmission zeros responses are designed and fabricated. The simulated and measured results prove the effectiveness of the proposed method.

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