A Multi-mode Cavity Filter with Jerusalem Cross Structure Resonator

J. J. Liu, Y. J. Chen, N. Xu, Y. H. Ren, G. X. Xu, C. L. Ji, Z. Y. Zhao, Y. Y. Zhang and R. P. Liu

State Key Laboratory of Meta-RF Electromagnetic Modulation Technology
Kuang-Chi Institute of Advanced Technology
Software Building, High-Tech Industrial Estate, Nanshan District, Shenzhen, China

Email: jingjing.liu@kuang-chi.org

***Abstract* — In this paper, a novel multi-mode dielectric resonator sandwiched by a Jerusalem Cross metal structure in the middle is proposed. This resonator has one degenerate dual modes and another nearby mode. These three modes are smartly used in a cylindrical cavity to generate two transmission zeros and one transmission pole. Therefore a single-cavity multi-mode bandpass filter is designed. In order to excite the three modes, two ports are placed orthogonally and another two tuning screws are needed to provide similar capacitance effects as the port pins. Simulation results show that the cavity with the resonator successfully becomes a bandpass filter and measurement results also prove this concept.**

***Index Terms* — Multi-mode cavity filter, dielectric resonator, Jerusalem Cross structure, transmission zero.**

I. Introduction

Communications systems develop rapidly and towards small sizes. The base stations in the systems require microwave cavity filters, which have low loss and can stand high power. However, the miniaturization of cavity filters becomes a bottleneck issue that prevent the system miniaturization. One of technique to solve this problem is to use multi-mode filters. It can be realized by a resonator creating degenerate modes, which have same resonant frequencies. Many efforts have been done in this area [1]-[3]. [1] used a dual-mode conductor-loaded ceramic resonator to make a dual-degenerate-HE-mode. Using two orthogonal square shaped ceramic, a cross-shaped resonator could operate as TE dual-mode [2]. To obtain better spurious performance, two through holes with different diameters are formed in the centre of the cross-shaped ceramic. Quad-mode dielectric resonator filters were introduced in [4], however, the tuning is very complicated. Normally, multi-mode filters need perturbation configurations to split degenerate modes and this increases the difficulty of tuning and fabrications.

This paper proposes a novel multi-mode dielectric resonator without extra perturbations. The filter with this resonator has one degenerate dual modes and another nearby mode. With proper excitation and tuning, one transmission pole(TP) and two transmission zeros(TZs) are realized to form a bandpass filter. The next section will describe the configuration of the novel multi-mode dielectric resonator and the third section will discuss the simulation results of the multi-mode filter. Measurement results will be shown in the fourth section and conclusions will be the final section.

II. Configuration of Proposed Resonator

The proposed multi-mode dielectric resonator consists of two layers of ceramics and a metal structure sandwiched in the middle. The cross-section view and side-view are shown in Fig. 1. The dielectric constant of the ceramics is 16 and the loss tangent is 0.004. The thickness of the metal structure in the figure is exaggerated for illustration purpose. The metal structure has the shape of Jerusalem cross and it can be regarded that four bars are connected by a cross. When the resonator is placed in a microwave environment, electrons in the metal structure move from one bar to another through the cross. Therefore the bars act as capacitors and the cross acts as inductors.

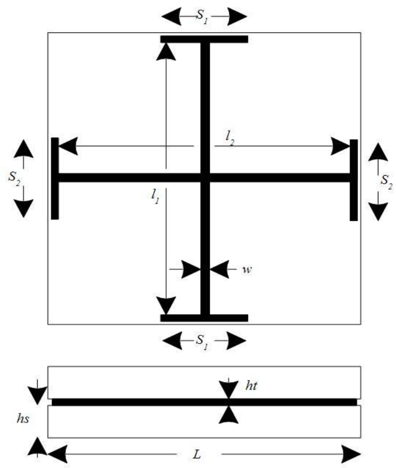

Fig. 1. Structure of the proposed multi-mode dielectric resonator, the top figure is the cross-section view at the metal structure layer, the bottom one is side-view. S_1 = 10.4mm, S_2 = 7.4mm, l_1 = l_2 = 19.4mm, w = 0.2mm, ht= 0.018mm, hs= 1mm, L = 20mm.

The resonator has three modes and the views of the E-field distribution are shown in Fig. 2. If S_1 is equal to S_2, Mode 1 and Mode 2 are orthogonal and have the same resonant frequency. This means they are degenerate modes. In order to split the degenerate modes, S_1 is set as a different value from S_2. This causes their equivalent capacitance different and therefore resonant frequencies are different. Mode 3 has a similar resonant frequency as the first two modes.

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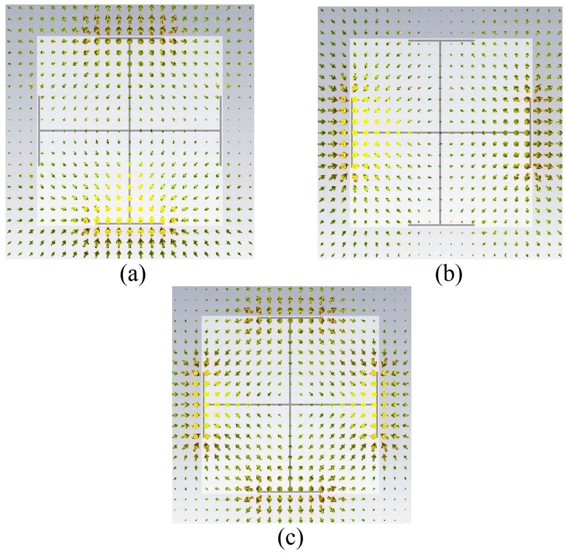

Fig. 2. The E-field distribution of the resonator, (a) Mode 1, (b) Mode 2, (c) Mode 3.

III. Simulations of Multi-Mode Filter

The resonator has three modes and in order to use the three modes to form a bandpass filter, the ports and tuning screws are needed to design smartly. Fig. 3 shows the top view of the filter, which is made by placing the resonator in a cylindrical cavity. The two ports are placed orthogonally and this configuration can excite all of the three modes. Mode 1 is excited by port 1, but its horizontal E-field component is weak. This means most of the energy of Mode 1 cannot be received by port 2 and therefore Mode 1 becomes a TZ. Similarly, Mode 2 is also a TZ. Mode 3 has both the horizontal and vertical E-field components and the energy can go through between the two ports and it becomes a TP. The two screws introduce similar capacitance effect as the two port pins and helps to tune the frequencies of TZs.

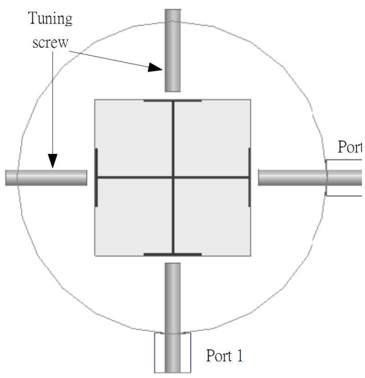

Fig. 3. Top view of the filter with the resonator showing the metal structure layer.

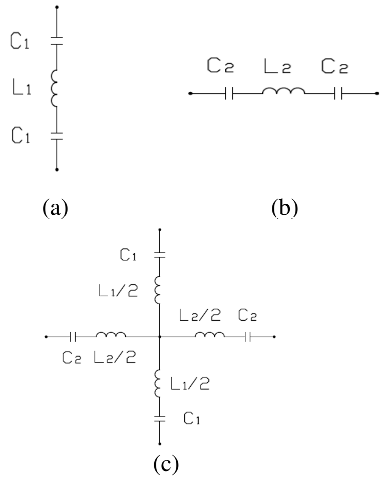

Fig. 4. The simplified equivalent circuits of the three modes, (a) Mode 1, (b) Mode 2, (c) Mode 3.

The simplified equivalent circuits of the three modes are shown in Fig. 4. In the Mode 1, electrons mainly go up and down under the electrical field, so the two horizontal bars (S_1) can be regarded as capacitors and the vertical bar (l_2) can be simply regarded as an inductor. Similarly, the other two mode equivalent circuits can be derived. When the resonator is placed in the cavity, the port pins and tuning screws increase the capacitance and therefore can move the mode frequencies. The equivalent circuit of the multi-mode filter is shown in Fig. 5. The Mode 1 becomes a zero and this means the signals go from Port 1 to GND1. The Mode 2 signals go from Port2 to GND2 and the Mode 3 signals go from port to port. The resonant frequencies of the three modes are shown in the following equations. In order to realize $f_{mode1} < f_{mode3} < f_{mode2}$, this requires $C_1 > C_2$, therefore S_1 is larger than S_2 in Fig. 1. The simulation results of the circuit in Fig. 5 are shown in Fig. 6. The C_2 value is fixed and three different C_1 values are simulated. There are two zeros and one pole as expected. The small C ($C=C_1-C_2$) causes two poles close to each other and gets better out-of-band rejection.

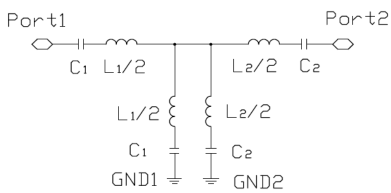

Fig. 5. The equivalent circuit of the multi-mode filter.

$$f_{mode1} = \frac{1}{2\pi\sqrt{L_1 \cdot \frac{C_1}{2}}} \quad (1)$$

$$f_{mode2} = \frac{1}{2\pi\sqrt{L_1 \cdot \frac{C_2}{2}}} \quad (2)$$

$$f_{mode3} = \frac{1}{2\pi\sqrt{L_1 \cdot \frac{C_1 \cdot C_2}{C_1 + C_2}}} \quad (3)$$

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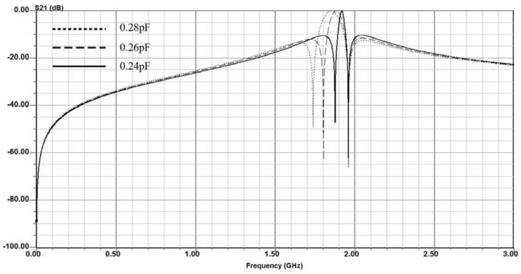


Fig. 6. The simulation results of the multi-mode filter equivalent circuit by Ansoft Designer. Three different C_1 values are simulated, L_1 and C_2 are fixed to be 60nH and 0.22pF respectively.

The multi-mode filter cavity has the diameter of 40mm and the height is 30mm. The size of the resonator is described in Fig. 1. The complete 3D model of the filter is simulated using CST Microwave Studio. The simulation results of the filter are shown in Fig. 7 and they match well with the equivalent circuit simulation results. The TP is at 1.842GHz and the two TZs are at 1.822GHz and 1.863GHz respectively. The S21 at the TP is 0.2dB. The better out-of-band rejection and wider bandwidth can be achieved by using more such filters.

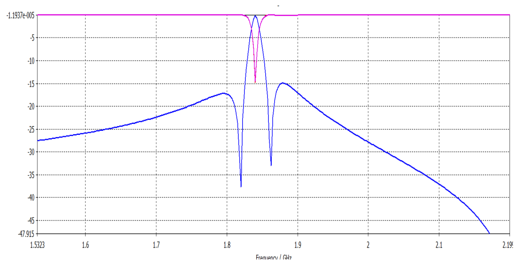
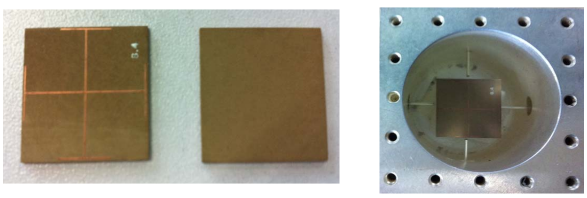


Fig. 7. The simulation results of the filter by CST, the bottom curve is S21 and the top curve is S11, the pole is at 1.842GHz.

IV. Measurement Results of the filter

The resonator was fabricated according to the size in Fig. 1 and the actual resonator is shown in Fig. 8(a). The cavity was also fabricated and shown in Fig. 8(b). The filter was tested using a network analyzer and the measurement result of S21 curve is shown in Fig. 9.



(a) (b)

Fig. 8. (a) The dielectric resonator with Jerusalem cross copper structure, (b) top view of the multi-mode filter.

The measurement results show that there are two TZs and the TP is at 1.86GHz. The frequencies are slightly different from the simulation results and this is possibly caused by the deviation of ceramic dielectric constant. The ceramics also introduce some high-order modes and these can be easily removed by a low-pass filter. The loss is about -2dB. Many factors cause the loss. For example, the ceramic has a low Q value (only 250) and the cavity is not coated by silver. It is believed that much better results can be achieved if high-Q ceramics and better fabrication are used. The measurement results prove the concept that the multi-mode filter has two TZs and one TP, and they form a pass band. This consists with simulation results.

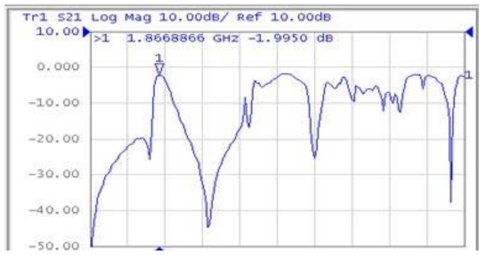


Fig. 9. Measurement result S21 curve of the filter. The transmission pole is at 1.86GHz.

V. Conclusion

In this paper, a novel multi-mode dielectric resonator is introduced. It consists of two layers of ceramics and a Jerusalem cross metal structure sandwiched in the middle. This special configuration can generate one degenerate dual modes and another mode nearby. These three modes are designed to form two TZs and one pole when placed in a cylindrical cavity. Simulation results show that a bandpass filter is achieved and this is further proved by measurement results.

Acknowledgement

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