Novel Compact Microstrip Dual-Mode Filters with Two Controllable Transmission Zeros

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Abstract ─ Novel compact pentagonal dual-mode filters by short-loaded are presented. The field patterns of this type of resonators are investigated using full-wave electromagnetic simulations. The technique of utilizing capacitive and inductive source-load coupling to improve the performance of filters is fully researched. Advantages of using this type of filter are not only its compact size, but also its transmission zeros that can be independently controlled. Then, two dual-mode bandpass filters are designed, fabricated and tested to validate the design. Good agreement is achieved between the measured results and simulated ones.

Index Terms ─ Bandpass filter, dual-mode, source-load coupling, transmission zero.

I. INTRODUCTION

Bandpass filter is one of the most important components in microwave circuits. To meet the requirement of modern microwave communication systems, microwave bandpass filters with compact size and high performance are in urgent demand. The dual-mode resonators are attractive because each resonator can be used as a doubly tuned circuit, and the number of resonators is reduced by half, resulting in a compact size. Wolff first demonstrated a microstrip dual-mode filter in 1972 [1]. Since then, dual-mode microstrip filters have been widely used in communications systems [2-3]. Among them, E-shaped microstrip resonators and filters have been originally reported [4]. More recently, the E-shaped resonator was modeled as a dual-mode resonator [5]. However, it was difficult to control the location of the transmission zeros. Circular dual-mode filter based on source-load coupling was proposed [6]. By introducing a capacitive cross-coupling between the input and output ports, the additional zero can be generated, but that can't be independently controlled. The open stub dual-mode filter with adjustable transmission zeros by inductive source-load coupling was firstly proposed [7-8]. Two novel bandpass filters with multiple transmission zeros using four open/shorted stubs were proposed [9-10]. The out-of-band transmission zeros can be adjusted easily by only changing the electrical length of the four open/shorted stub. But the resonator occupied a large circuit area, size reduction is becoming a major design consideration for modern practical applications. Two filters [11], with pentagonal dual-mode resonator and capacitive/inductive S-L coupling, have been designed and fabricated in the last two years. Which show good stopband rejection with adjustable transmission zeros.

In this paper, two compact bandpass filters with a pentagonal dual-mode resonator and source-load coupling are introduced. The reduction of the size is achieved by using a pentagonal dual-mode resonator. Furthermore, with a cross-coupling between the input and output feed lines, two tunable transmission zeros are obtained. The transmission zeros can be controlled independently by changing the amount of the capacitive or inductive source-load coupling. The proposed bandpass filter shows a good stopband rejection because of the two tunable transmission zeros. Two practical filters verify the feasibility of the technique.

II. DUAL-MODE PENTAGONAL RESONATOR

Figure 1 shows the geometry of proposed dual-mode filters with the pentagonal open-loop resonator with short-loaded. The filter comprises an improved pentagonal half-wavelength resonator and a short-loaded stub. A via hole was used to achieve the required short. The source-load coupling include two types, i.e., capacitive and inductive.

The proposed dual-mode filter can be equivalent to a T-shaped resonator model with a half-wavelength resonator and an inductance-loaded element as shown in Fig. 2. Z_1 is the characteristic impedance of the half-wavelength resonator with the electrical length $\theta_1 = 90$. L_1 is the equivalent inductance of the short-loaded stub. C_1 is the coupling capacitance between resonator and feed line. A via hole was used to achieve the required inductance. The usage of short-loaded stub saves the circuit size compared with that of open-loaded stub.

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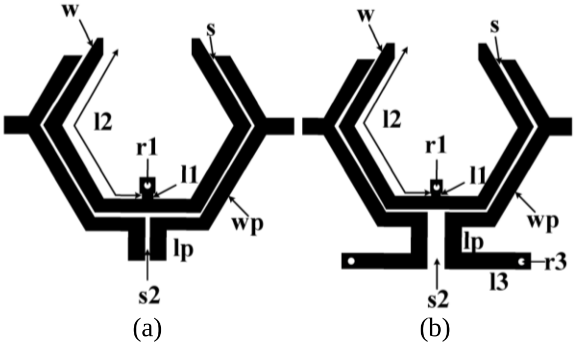

Fig. 1. Layout of the proposed pentagonal dual-mode bandpass filter. (a) Capacitive source-load coupling, and (b) inductive source-load coupling.

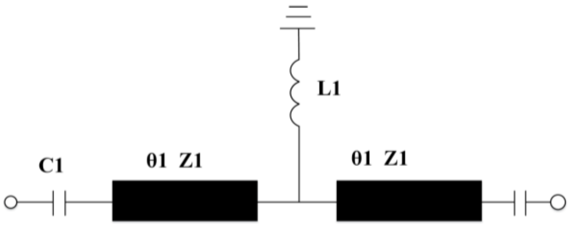

Fig. 2. Schematic of a half-wavelength resonator with an inductance-loaded.

For a compact size, the half-wavelength lines are bent to a pentagon. The via hole at the centre of the resonator introduces another transmission pole near the fundamental frequency of the half-wavelength resonator. This new pole and the fundamental frequency pole make the proposed structure a dual-mode resonator. So this symmetric structure can support two modes, i.e., an even mode and an odd mode.

The commercially available full-wave electromagnetic simulators (HFSS) were used to characterize the electric field patterns for the dual-mode resonator. HFSS uses the finite element method (FEM) to analyze the electromagnetic characteristics of 3D objects. The basic process of solving the problem by FEM includes three parts, which are the mesh discretization of the object, the solution of the simultaneous matrix equations related the mesh and the postprocessing calculation of the problem.

It can be seen that the whole structure is symmetrical with the center point, so the center point is modeled as the origin point and the mirror operation is applied. The physical excitation of the filter is by the coaxial line with the TEM wave. In order to use the wave-guide port in the simulation code, the port surface must cover more than ninety-five percent of the TEM field. It is assumed that the width of the excitation microstrip is w and the thickness of the dielectric layer is h. The height of the wave port is generally set to 6~10h. When w>h, the width of the wave port is set to about 10w; when w<h, the width of the wave port is set to about 5w. Finally, the height and width of the wave port are 10h and 10w in this paper.

According to the standard which is set up by user, HFSS simulation code uses adaptive mesh generation technology. The solution frequency of the meshing is generally set at the center frequency of the filter. After each new mesh subdivision, HFSS will compare the results of the S parameters with the old one. If the error is less than the set criterion, it is shown that the result is convergent and the adaptive process will end. The dimensions are optimized by a full-wave simulation to take all the discontinuities into consideration.

Figure 3 depicts the simulated electric field vector between the metal strip and ground plane at the resonance frequency. The electric field pattern of the odd mode is illustrated in Fig. 3 (a), where the maxima of the field are located along the left and right arms and no fields on the loaded-element. The field distribution is similar to that of a half-wavelength single-mode resonator. As a consequence, the short-loaded element does not affect the resonant frequency of the odd mode. Figure 3 (b) shows the electric field pattern of the even-mode, where the maxima of the field are also located along the two arms, but part of the fields moved to the loaded-element. Moreover, it is observed from the direction of the electric field vector that the field is symmetric with respect to the symmetry axis. Hence, changing the dimension of the short-loaded element makes the resonant frequency of the even mode shift. The two resonant poles can be adjusted independently.

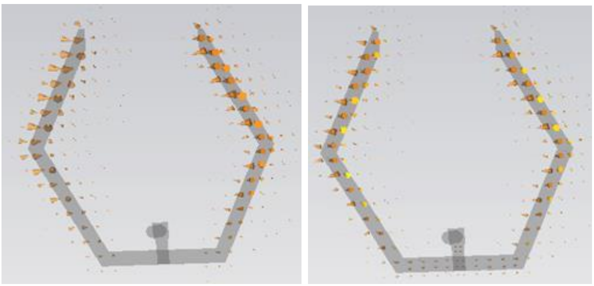
(a) (b)

Fig. 3. Electric field patterns for the pentagonal dual-mode resonator: (a) odd mode and (b) even mode.

To observe the mode splitting, the pentagonal dual-mode resonators have been simulated using a full-wave EM eigen-mode solver with different loaded element size. The simulated resonant frequencies of the two modes are plotted in Fig. 4 as a function of the size l_1 and l_2.

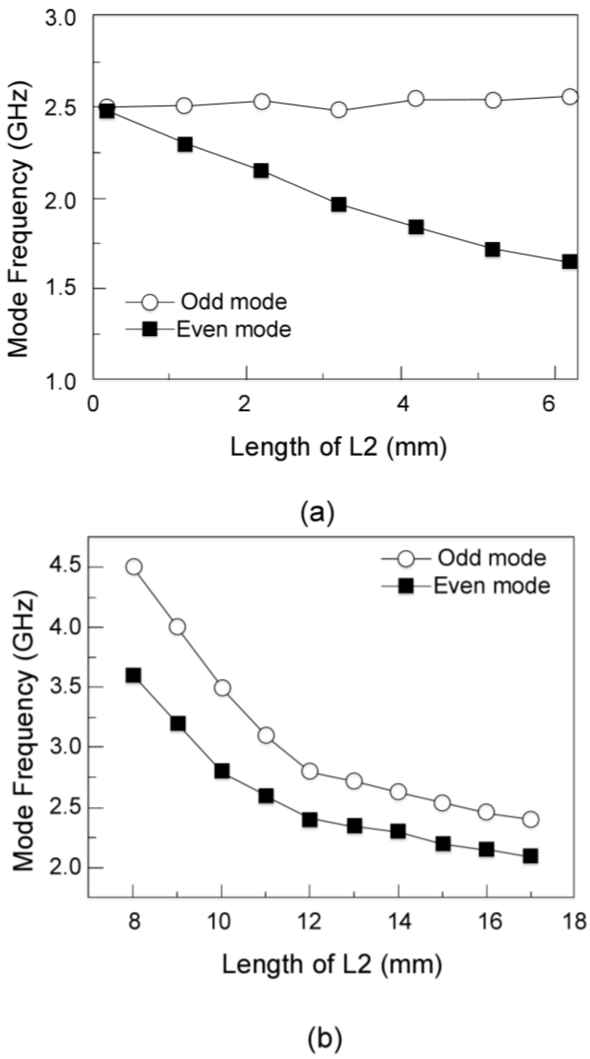

Fig. 4. Resonance frequencies of the two modes against: (a) l_1, where l_2 = 15 mm, (b) l_2, where l_1 = 0.8 mm for short-loaded resonator.

When l_1 increases from 0.2 to 6.2 mm, the resonant frequency of the even mode decreases from 2.48 to 1.7 GHz, while that of the odd mode hardly change. l_2 will affect both the even and odd mode.

III. BANDPASS FILTERS USING PENTAGONAL DUAL-MODE RESONATOR

Figure 1 shows the layout of the proposed pentagonal dual-mode bandpass filter. It consists of the capacitive source-load coupling filter and inductive one. The gap between the resonator and feed line was selected in consideration of strong coupling and etching tolerance. The length of the source-load coupling line is l_P. The characteristic impedance of the input/output feed line is taken as 50 ohm.

By investigation, the dual-model filter has an interesting property. There is an inherent finite-frequency transmission zero when the two modes split. If the frequency of even mode is less than that of odd mode, the inherent transmission zero would be in the lower stopband. If the frequency of even mode is greater than that of odd mode, the inherent transmission zero would be in the upper stopband. As shown in Fig. 4, the frequency of the even mode is always less than that of the odd mode for the short-loaded resonator, so the inherent transmission zero would be in the lower stopband.

For further improving the filters' performance, the source-load coupling is introduced to generate an additional transmission zero. By our research, the locations of the additional transmission zeros can be controlled by transforming the amount and type of the source-load cross-coupling. For the inductive coupling, the additional transmission zero will be in the lower stopband. While, for the capacitive coupling, the additional transmission zero will be in the upper stopband. So, the response with two adjustable transmission zeros can be obtained for the proposed filters. Two sample filters verify the feasibility of the new technique.

A. Dual-mode filter with capacitive S-L coupling

Filter A demonstrates a filtering characteristic with the finite transmission zeros in the both lower and upper stopband. As it has been noted, for the short-loaded dual-mode filter, the inherent transmission zero would be in the lower stopband. So, the capacitive source-load coupling is introduced to generate the additional zero in the upper stopband. The transmission zeros can be controlled by changing the amount of the source-load coupling. As shown in Fig. 5, when s2 decreases from 0.8 to 0.2 mm, the transmission zeros move toward the passband edge with better stopband rejection. Also, the selectivity can be improved when l_P increases as shown in Fig. 6. Therefore, the amount of cross-coupling can be selected to meet the required filter selectivity.

Figure 7 shows the photograph of the fabricated filter A. The simulated and measured results are shown in Fig. 8. As shown in Fig. 8, the filter A operated at 2.75 GHz and a 3 dB fractional bandwidth of 9.5%. The minimum insertion loss is about 1.4 dB, and the return loss is greater than 15 dB in the passband. Two transmission zeros are located at 2.27 GHz and 3.44 GHz respectively, which provide a better cutoff rate in the stopband.

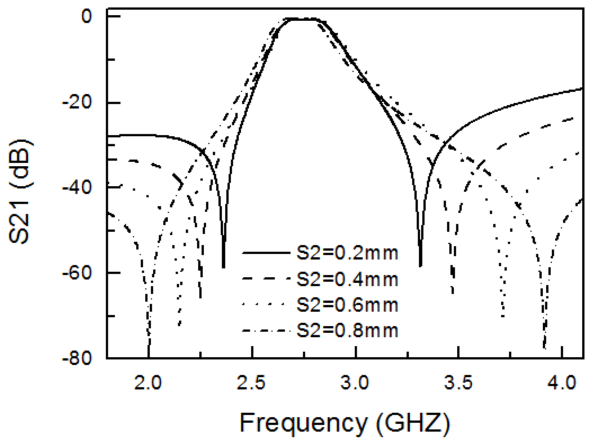

Fig. 5. Simulated scattering parameters of the filter A against s_2.

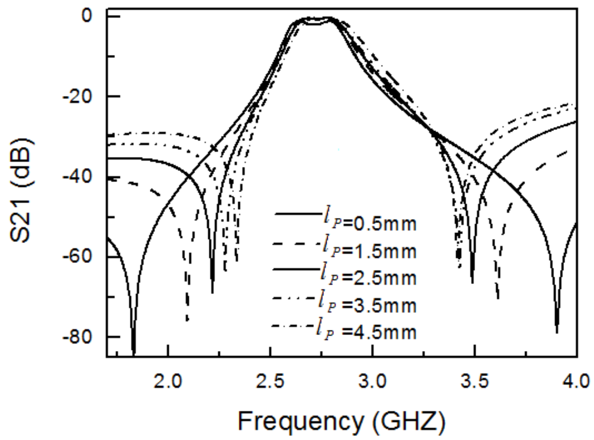

Fig. 6. Simulated scattering parameters of the filter A against l_p.

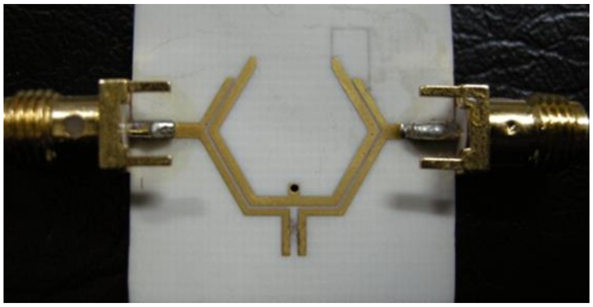

Fig. 7. Photograph of the fabricated filter A.

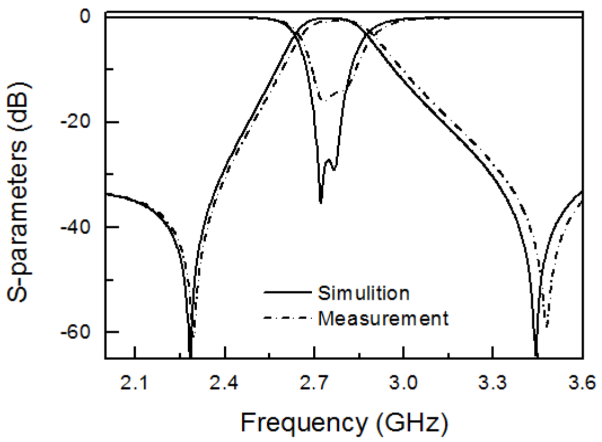

Fig. 8. Simulated and measured results of the filter A.

B. Dual-mode filter with inductive S-L coupling

Filter B demonstrates a filtering characteristic with the both finite transmission zeros in the lower stopband. The inherent transmission zero is in the lower stopband for short-loaded filter. Also, the inductive source-load coupling is introduced to generate the additional zero in the lower stopband. Figure 9 and Fig. 10 show the simulated s_{21} as a function of the s_2 and l_P. The inner transmission zero is the inherent zero, and the outer one is the additional transmission zero. The inherent transmission zero hardly changes, but the additional one can be distinctly controlled by the amount of source-load coupling.

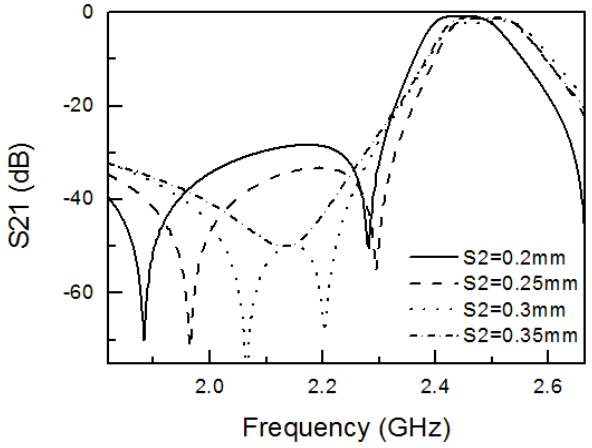

Fig. 9. Simulated scattering parameters of the filter B against s_2.

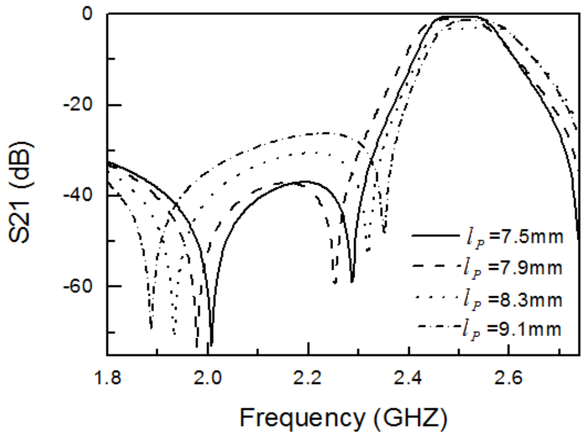

Fig. 10. Simulated scattering parameters of the filter B against l_p.

Figure 11 shows the photograph of the fabricated filter B. The measured and simulated results are shown in Fig. 12. The measured center frequency is at 2.45 GHz, and the 3 dB bandwidth is 4.6%. The minimum measured insertion loss is 1.8 dB, and the return loss is greater than 15 dB in the passband. Two transmission zeros are located at 2.04 and 2.15 GHz. The measured results have a good agreement with the full-wave simulations.

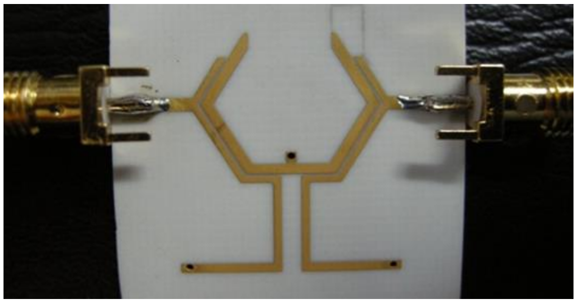

Fig. 11. Photograph of the fabricated filter B.

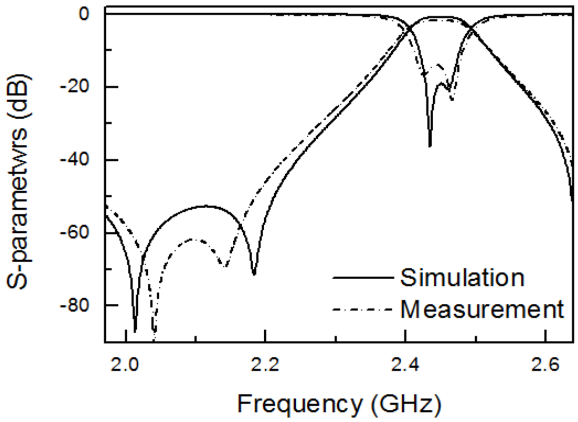

Fig. 12. Simulated and measured results of the filter B.

For the comparison with the previous investigations, Table 1 summarizes some dual-mode BPF performance characteristics. In the Table 1, the λg is the guided wavelength at the center frequency. It can be seen that the presented two dual-mode BPF shows miniature size when compared with the previous works.

Table 1: Comparison between the reference filters and the proposed filter

Reference	Center Frequency (GHz)	Insertion Loss (dB)	Return Loss (dB)	Filter Size
Ref.3	6.95	1.8	11.5	0.3λg×0.15λg
Ref. 5	2.4	2.0	15.5	0.25λg×0.16λg
Ref. 7	3.5	0.9	20	0.15λg×0.12λg
Ref. 9	4	1	15	0.51λg×0.51λg
This work	2.75 2.45	1.4 1.8	15 15	0.1λg×0.1λg 0.1λg×0.12λg

IV. CONCLUSION

The novel compact pentagonal dual-mode filter with short-loaded is presented. The application of capacitive and inductive source-load coupling has been studied intensively to improve the performance in this paper. It reveals that a quasi-elliptic response with two adjustable transmission zeros is obtained for high rejection level in the stopband. The proposed structure and design method is verified by two sample filters.

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REFERENCES

[1] I. Wolff, “Microstrip bandpass filter using degenerate modes of a microstrip ring resonator,” *Electron. Lett.*, vol. 8, pp. 302-303, June 1972.

[2] B. F. Ganji and M. Samadbeik, “Simple configuration low-pass filter with very wide stop band,” *ACES Express Journal*, vol. 1, no. 1, pp. 4-7, 2016.

[3] X. Deng, Z. Wang, K. D. Xu, and B. Yan, “Novel microstrip ultra-wideband bandpass filter using radial-stub-loaded structure,” *ACES Express Journal*, vol. 1, no. 1, pp. 20-23, 2016.

[4] J. R. Lee and J. H. Cho, “New compact bandpass filter using microstrip λ/4 resonator with open stub inverter,” *IEEE Microw. Guided Wave Lett.*, vol. 10, no. 12, pp. 526-527, Dec. 2000.

[5] T. Yan, X. H. Tang, and J. Wang, “A novel quad-band bandpass filter using short stub loaded E-shaped resonators,” *IEEE Microwave & Wireless Components Letters*, vol. 25, no. 8, pp. 508-510, Aug. 2015.

[6] W.-H. Wu, “Compact double-mode cross-coupled microstrip bandpass filter with tunable transmission zeros,” *IET Microw. Antennas Propag.*, vol. 2, no. 4, pp. 373-377, Dec. 2008.

[7] L. Gao and X. Y. Zhang, "High-selectivity dual-band bandpass filter using a quad-mode resonator with source-load coupling," *IEEE Microwave & Wireless Components Letters*, vol. 23, no. 9, pp. 474-476, Sept. 2013.

[8] J.-S. Hong and H. Shaman, "Dual-mode microstrip open-loop resonators and filters," *IEEE Trans. Microw. Theory Tech*., vol. 55, no. 8, pp. 1764-1770, Aug. 2007.

[9] W. Feng, X. Gao, and W. Che, "Bandpass filters with multiple transmission zeros using open/ shorted stubs," *IET Microw., Antennas Propag*.,vol. 9, no. 8, pp. 769-774, June 2015.

[10] B. Yu, B. Jia, and Z. Zhu, "Compact tri-band bandpass filter with stub-loaded stepped-impedance resonator," *Electron. Lett*., vol. 51, no. 9, pp. 701-703, Apr. 2015.

[11] Z. Zhu, S. Liang, and C. Wei，"Novel pentagonal dual-mode filters with adjustable transmission zeros," *ACES Express Journal*, vol. 31, no. 10, pp. 1238-1243, 2016.

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