具曲折型饋入線之雙頻陶瓷帶通濾波器

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摘要

在目前無線通訊系統的應用上，爲了縮小化和雙頻(2.4 and 5.7 GHz)操作的目的，在本研究中，一對修正型背對背步階阻抗共振器被含於一對修正型曲折型耦合線之中來形成一個緊緻的結構。由於採用了高品質因數及高介電常數的氧化鋁(Al_2O_3)陶瓷基板，濾波器之特性可以被改善並且其尺寸可以縮小到僅僅 22.2 mm × 12 mm。另一方面，調整修正型背對背步階阻抗共振器之阻抗比例(*K* 值)，更可以遷移其第二共振頻率(二次諧波)至一合適的頻率，並且，修正型曲折型耦合線更可以用來激發額外的傳輸零點來改善濾波器之功能。在此研究中，由於組合了修正型曲折型耦合線和修正型背對背步階阻抗共振器，對於 2.4 GHz 而言，所製作的雙頻帶通濾波器之最佳量測的插入損失和頻寬分別爲 0.98 dB 和 11.1 %，而對於 5.7 GHz 而言，其最佳量測的插入損失和頻寬分別爲 1.05 dB 和 10.1 %。

關鍵字：耦合線、雙頻、步階阻抗共振器

Dual-Band Bandpass Ceramic Filters with Meandering Feeding Lines

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Abstract

In the applications of modern wireless communication systems, for the purpose of miniaturization and dual-band (2.4 and 5.7 GHz) operations, a pair of modified back-to-back stepped impedance resonators (SIR) were involved in a pair of modified meandering coupled lines to form a compact structure in this research. Owing to the high quality factor and dielectric constant Aluminum Oxide (Al_2O_3) ceramic substrate was used, the characteristics of this filter could be improved and the size of the filters could be minimized to only 22.2 mm × 12 mm. Furthermore, the modified back-to-back SIR structures could be used to adjust the second resonant frequency (second harmonic) to a suitable frequency by adjusting of the impedance ratio (*K* values), and the modified meandering coupled line structures could be used to excite additional transmission zeros to improve the performance of the proposed filter. In this research, by the combination of the modified meandering coupled lines and the modified back-to-back SIR, the optimum measured insertion loss and bandwidth of the proposed dual-band bandpass filter for 2.4 GHz are 0.98 dB and 11.1 %, respectively. And the optimum measured insertion loss and bandwidth of the proposed dual-band bandpass filter for 5.7 GHz are 1.05 dB and 10.1 %, respectively.

Key words: Coupled line, dual-band, stepped impedance resonator

Ⅰ. Introduction

In the past, miniaturization, multi-bands, low profile, and low cost were the main tendencies of the modern wireless communication components. Especially, the planar microstrip line is the most popular structure because that is easy to design, analysis, and miniaturization. An open-loop resonator with magnetic coupling is a popular method to design the microstrip filters [1]. In [2], by the use of the cross-coupled hairpin resonators, a dual-band bandpass filter (BPF) (2.4/5.2 and 2.45/5.7 GHz) could be achieved easily, and two deep transmission zeros could be generated beside the pass-bands. In [3], a planar filter with a dual-passband (2.4/5.2 and 2.45/5.7 GHz) elliptic function response was presented. And in [4], an alternately cascaded multi-band resonator was used to design the dual-band and tri-band BPF, and the mutual coupling between the resonators almost did not occur. In [5], a pair of right/left meandering structure was used to design a compact CPW bandpass filter. In [6], the meandered parallel coupled lines were used to compress the spurious passband of the microstrip filter.

Base on above design concepts, in this letter, two back-to-back stepped impedance resonators (SIR) are combined together with a pair of open-stub 50-Ω modified meandering coupled lines to form a compact dual-band (2.4 and 5.7 GHz) BPF. In addition, the harmonic (f_2) is controlled by the normalized ratios (f_2/f_1) of the SIR structures only. In this design, the modified meandering coupled lines can enhance the coupling between the resonators and the coupled lines, further controlled the positions and number of the transmission zeros and hence can improve the characteristics of the stop-bands. Moreover, the filter is screen-printed on the high dielectric constant (relative dielectric constant is 9.8) and high quality factor (loss tangent is assumed as 0.001) Aluminum Oxide (Al_2O_3) ceramic substrate (thickness is 1 mm), which can further reduce the size and improve the characteristics of the filters. Both of the simulated and measured results of the proposed filters can achieve the requirements (-3 dB bandwidth > 10 %, insertion loss < 1 dB) of dual-band operations.

Ⅱ. Experimental

1. The Modified Back-to-Back SIR Structure: Generate Two Operating Frequencies (2.4 and 5.7 GHz)

In order to generate two operating frequencies (2.4 and 5.7 GHz), the stepped impedance resonator (SIR) structures were adopted and calculated by the use of the impedance ratio ($K=Z_2/Z_1$), whereas the harmonic (f_2) can be adjusted by the changes of the K value [7]. In this design, the central frequency (f_1) is designed at 2.4 GHz for WLAN applications, and because the center frequency is controlled by the wavelength λ only and do not change apparently as the K values vary. Therefore, by the use of the SIR structure with K <1, the harmonic f_2 can be shift to be greater than $2f_1$ (to 5.7 GHz in this design) easily. And for the purpose of miniaturization, two compact modified back-to-back SIR structures [8, 9] are designed and shown in Fig. 1, in addition, the magnetic coupling is happened between them. The simulated coupling coefficients due to the variation of the gap S of these two back-to-back modified SIR resonators are also shown in Fig. 1. As the gap S increases, both of the coupling coefficients for 2.4 GHz and 5.7 GHz decrease gradually. And it can be observed that as the gap S=0.6 mm, the coupling coefficient for 2.4 GHz is just the same as the coupling coefficient for 5.7 GHz. This means that the optimum gap S of the modified back-to-back modified SIR will be 0.6 mm. And the other designed parameters of this modified back-to-back SIR structures are K=0.3 mm, L=0.4 mm, M=0.5 mm, and N=3.5 mm, respectively.

2. The Modified Meandering Coupled Line Structure: Generate and Adjust the Transmission Zeros

For an electromagnetic wave propagates in a dielectric, its velocity would be:

$$V = \frac{c}{\sqrt{\varepsilon_r}} = f \times \lambda \quad (1)$$

Where c is the velocity of light (3×10^{11} mm/sec), ε_r is the relative dielectric constant of the dielectric (for Al_2O_3, ε_r=9.8), f is the frequency, and λ is the wavelength. Substituting above values and after calculating, Eq. (1) will turn to be:

$$95.8(mm) = f(GHz) \times \lambda(mm) \quad (2)$$

Because the maximum voltage is happened at the open-ends, the resonating effect will happen at odd multiplication of the ¼λ, that is, the band-rejected effect will happen at this length. Hence, the position of the transmission zeros are located at:

$$l(mm) = n \times \frac{1}{4}\lambda(mm), n = 1,3,5,7........ \quad (3)$$

Fig. 2(a) shows the S_{21} results of the 50-Ω ¼λ coupled line structures (length=10.7 mm and width=1 mm) with two open-stubs (length=l), it is found that as the length of the open-stub is zero (that is an end-coupled line), no transmission zeros can be found and its S_{21} results still keep lower than -20 dB. As the open-stubs increases, the open stubs reveal the effect of band-rejection and can be considered as branch resonators. It is found that the addition of this open-stubs do not affect the impedance matching apparently but only the electric length. Detailed characteristics of the first theoretical and simulated transmission zeros are listed in Table 1, in addition, the first (n=1, λ=4×l) theoretical transmission zeros are calculated from Eq. (2) and Eq. (3), and the first simulated transmission zeros are simulated by the HFSS simulator. It is found that the simulated transmission zeros are good agree with theoretical ones.

In order to containing the modified back-to-back SIR structures discussed in Part 1, the open-stub in Fig. 2(a) is bended and shown in Fig. 2(b). Comparing Fig. 2(b) with Fig. 2(a), it is found that the S_{21} results of Fig. 2(b) are deeper than that in Fig. 2(a), and the frequencies of the transmission zeros are almost no changed (check l = 7 mm case). This means that the frequencies are decided by the length of open-stubs only and the shapes of the open-stubs do not affect the frequencies apparently. It also can be found in Fig. 2(b) that as the length of the open-stubs increase, the number of the transmission zeros will increase (check l = 20.2 mm case). This means that for the purpose of increasing the number and adjusting the frequencies of the transmission zeros, suitable selection of the length of the open-stubs (l) will be a good selection, and that can let the transmission zeros shift to proper locations (inside the stop-bands or just beside the pass-bands) and even increase the number of the transmission zeros. The first (n=1) theoretical and simulated transmission zeros for this meandering shape modified coupled line structures are listed in Table Ⅱ, the simulated transmission zeros are good agree with theoretical ones.

3. Combination of the Modified Back-to-Back SIR Structure and the Modified Coupled Lines Structure

The detailed parameters of the designed compact filter are shown in Fig. 3, and in addition, the modified back-to-back SIR structures have been put into the modified meandering coupled line structures. It is found that dual-band (2.4 and 5.7 GHz) operations can be achieved easily by the adding of the modified back-to-back SIR structures. And owing to the modified meandering coupled line structures are used, much more transmission zeros can be added into the stop-bands to improve the characteristics of the filter.

Ⅲ. Results and Discussion

The simulated and measured S_{21} and S_{11} results are shown in Fig. 4. The central frequency and the second operating frequency are located at 2.4 and 5.7 GHz, and all the simulated and measured stop-bands are all below -20 dB. For the simulated results, the transmission zeros are located at 1.16, 3.1, 3.95, 4.6, and 6.78 GHz, respectively. And for the measured results, the transmission zeros are located at 1.28, 3.2, 4.1, 4.84, and 7.03 GHz, respectively. For the central frequency (2.4 GHz), the optimum simulated and measured S_{21} are -0.14 dB and -0.98 dB, the optimum simulated and measured -3 dB bandwidth are 14.8 % and 11.1 %. And for the second operating frequency (5.7 GHz), the optimum simulated and measured S_{21} are -0.98 dB and -1.05 dB, the optimum simulated and measured -3 dB bandwidth are 14.8 % and 10.1 %. Due to good impedance matching, it can be observed in Fig. 4(b) that all the simulated and measured stop-band S_{11} are below -20 dB. Due to the dielectric loss of Al_2O_3 is assumed as 0.001 (indeed, the dielectric loss of Al_2O_3 is less than 0.001) and the error of fabricated processes, the measured and simulated results reveal a little mismatch. The detailed simulated and measured results are listed and concluded in Table 3 and the photograph of the proposed filter is shown in Fig. 5, which reveals a compact size of 22.2 mm $\times$ 12 mm only.

Ⅳ. Conclusion

By the adding of a pair of modified back-to-back SIR into a pair of meandering shape coupled lines, a dual-band (2.4 and 5.7 GHz) bandpass filter is developed and screen-printed on the Al_2O_3 ceramic substrate. Additional transmission zeros can be generated in the stop-bands or beside the pass-bands due to the adding of the open-stubs in the coupled line structures. And which could form a band-rejected branch resonator to compress the useless pass-bands and improve the characteristics of the proposed filter. The major purpose of the inside modified back-to-back SIR was to resonate 2.4 and 5.7 GHz passbands, moreover, and the major purpose of the outside modified meandering coupled lines was to excite additional transmission zeros and adjust its locations. In this design, the transmission zeros, the stop-bands, and even the operating frequencies can be controlled by different parameters independently and further let the design procedures become simple. All the characteristics of the filter in this research are suitable for the applications of modern WLAN communication systems, and a simple design concept of the transmission zeros is presented.

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Table 1 First Theoretical and Simulated Transmission Zeros of the Coupled Lines

Open stub *l* (mm)	λ (mm)	Theoretical transmission zeros (GHz)	Simulated transmission zeros (GHz)
0	–	–	–
3	12	7.98	6.8
7	28	3.42	3.22
12	48	2	1.9

Table 2 First Theoretical and Simulated Transmission Zeros of the Meandering Modified Coupled Lines

Open stub *l* (mm)	λ (mm)	Theoretical transmission zeros (GHz)	Simulated transmission zeros (GHz)
7	28	3.42	3.37
10	40	2.39	2.33
14	56	1.71	1.72
15.7	62.8	1.52	1.46
20.2	80.8	1.18	1.17

Table 3 Optimum Simulated and Measured Results of the Proposed Filters

Frequency (GHz)	S_{21} (Simulated/Measured) (dB)	Bandwidth (Simulated/Measured) (%)
2.4	-0.14/-0.98	14.8/11.1
5.7	-0.98/-1.05	14.8/10.1

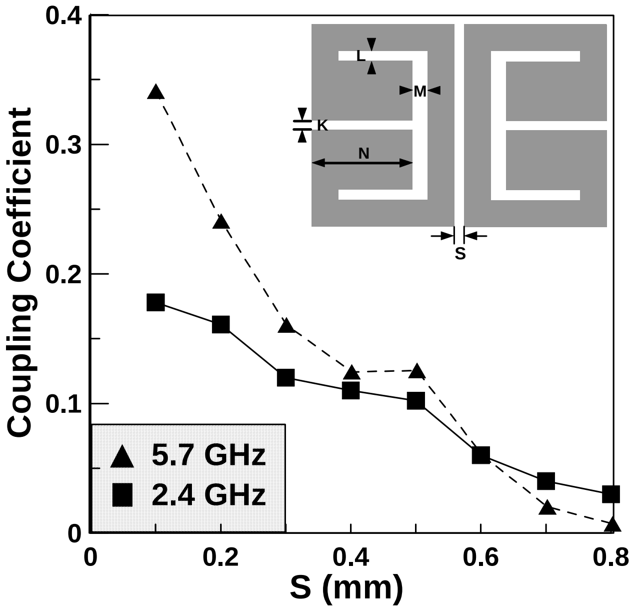


Fig. 1. The coupling coefficients of the compact modified SIR structure.

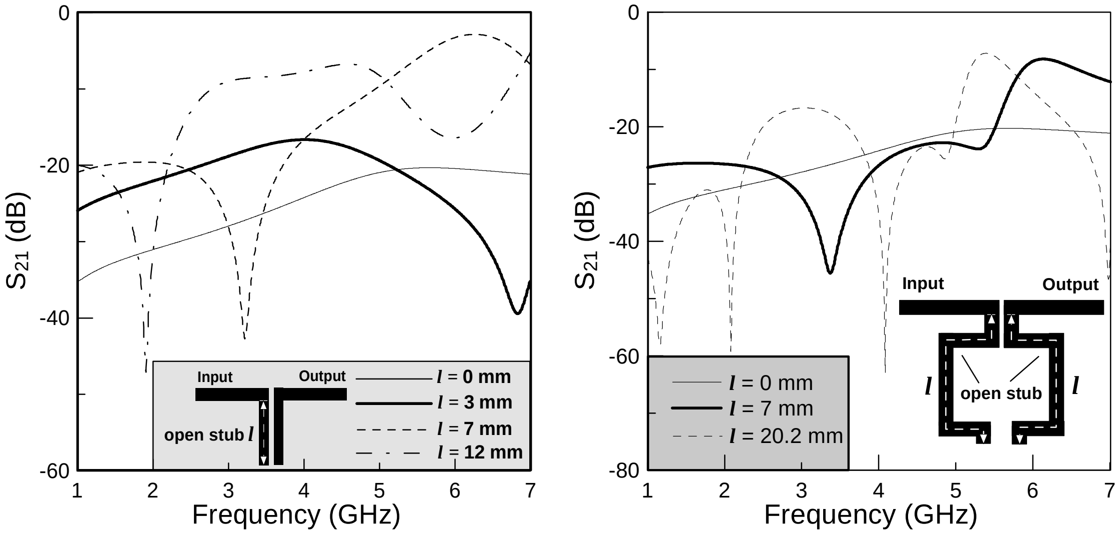


Fig. 2. Simulated S_{21} results for (a) the coupled lines with open-stubs ***l***.
(b) the meandering modified coupled lines with open-stubs ***l***.

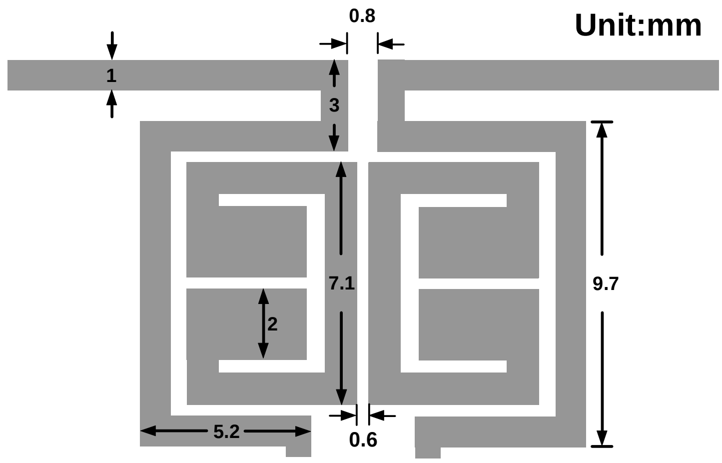
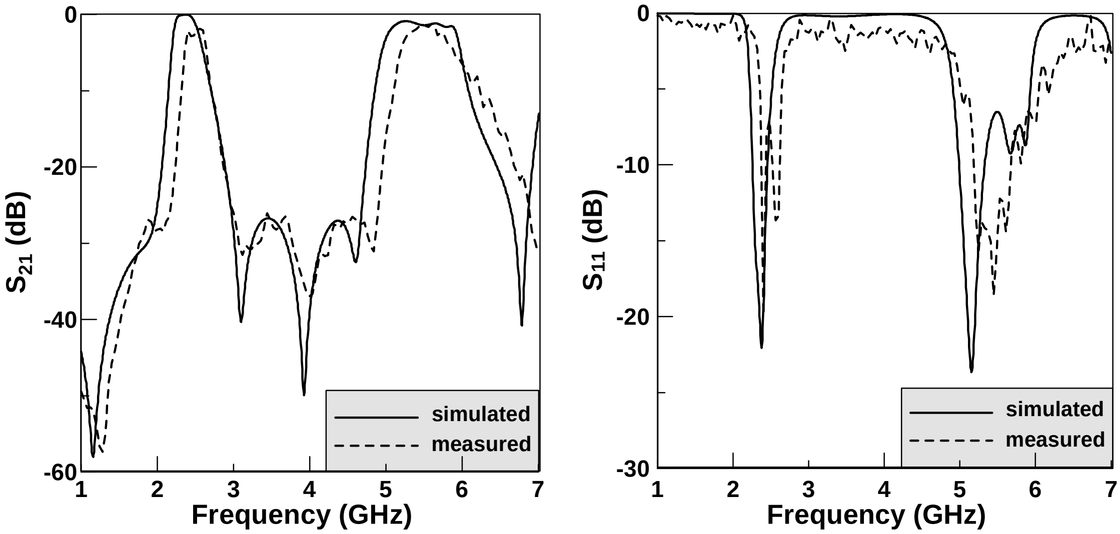


Fig. 3. The combination of the modified SIR and meandering modified coupled lines.



(a) (b)

Fig. 4. Simulated and measured (a) S_{21} (b) S_{11} of the proposed filter.

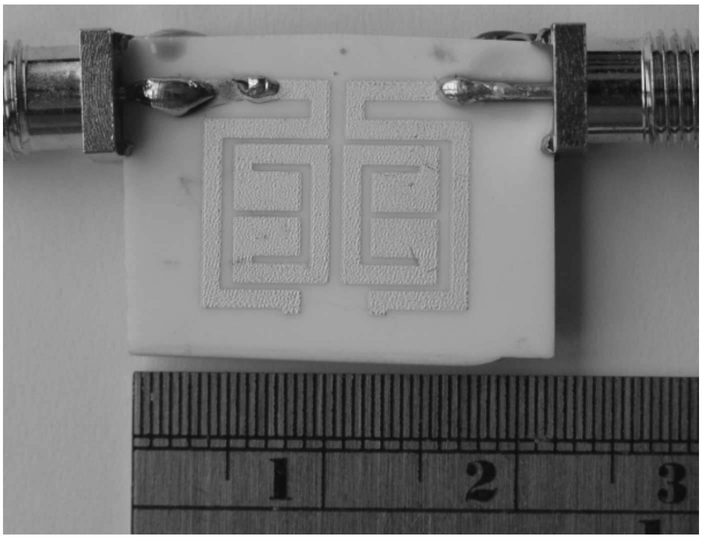


Fig. 5. The photograph of the proposed BPF.