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DESIGN OF A DUAL-MODE DUAL-BAND FILTER USING STEPPED IMPEDANCE RESONATORS

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Abstract—A microstrip dual-mode dual-band bandpass filter using stepped impedance resonators (SIRs) is designed for dual-band wireless local area networks (WLANs) applications at 2.4/5.2 GHz. By appropriately selecting the impedance ratio (R_z) and length ratio (α) of the SIRs, the harmonic frequencies can be tuned for generating the dual-bandpass response. Based on SIRs, a dual-mode dual-band bandpass filter is designed with one transmission zero. To improve the selectivity, another three transmission zeros in stopbands are created by introducing two stubs in input/output (I/O) lines. Two experimental filters are fabricated. Both simulated and measured results are presented.

1. INTRODUCTION

Modern development in wireless communication systems has increased demands for dual-band bandpass filter. To meet the demands, much research has been done. In [1], a dual-band bandpass filter was implemented by a cascade connection of two single-band filters. However, this approach not only consumes twice the size of a single-band filter, but also requires extra impedance matching networks. In [2], a resonator is embedded in another one to achieve two passbands. It can also realize a dual-band filter by combining two sets of resonators with common input and output [3]. In [4], Zhang designs dual-band bandpass filter using stub-loaded resonators. Defected ground structure is also used to achieve dual-band filter [5, 6]. In the past years, a lot of dual-band bandpass filters have been achieved with SIRs, due to the advantages of their harmonic frequencies behavior, simple structures, and simple-established design methodology [7–10].

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In this paper, we also propose a dual-mode dual-band bandpass filter by SIRs with new coupling structure. It shows that with the new coupling structure the filter has good passbands performance. To improve the selectivity, another three transmission zeros have been introduced by two stubs added in I/O lines.

2. DUAL-MODE DUAL-BAND BANDPASS FILTER WITH $\lambda/2$ SIRs

Figure 1(a) shows the basic structure of a half-wavelength ($\lambda/2$) microstrip SIRs, which is constructed by cascading a long-length ($2\theta_1$) high-impedance section (Z_1) in the center connected with the two short-length (θ_2) low-impedance section (Z_2) in the two sides.

For odd-mode excitation, the middle of SIRs is equal to electrical wall; the approximate equivalent circuit is shown in Fig. 1(b). The fundamental resonance (f_0) occurs at [8]:

$$R_z = \tan(\theta_1)\tan(\theta_2) \tag{1}$$

where R_z is the ratio of characteristic impedance Z_2 to Z_1. For even-mode excitation, the middle of SIRs is equal to magnetic wall; the approximate equivalent circuit is showed in Fig. 1(c). The fundamental resonance (f_0) occurs at [8]:

$$R_z = -\cot(\theta_1)\tan(\theta_2) \tag{2}$$

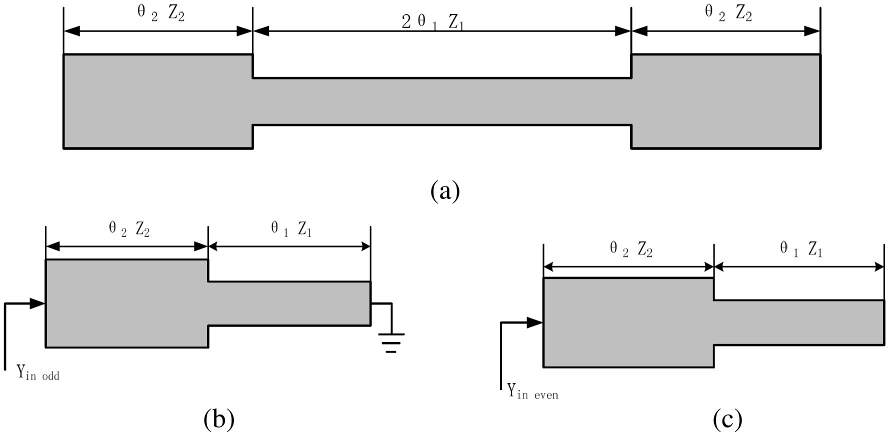


Figure 1. (a) Structure of $\lambda_g/2$ SIRs. (b) Odd-mode equivalent circuit. (c) Even-mode equivalent circuit.

In most practical application, we often chose $\theta_1 = \theta_2 = \theta_0$. In this situation, the first spurious resonance occurs at [7]:

$$\tan(\theta_{s1}) = \infty \tag{3}$$

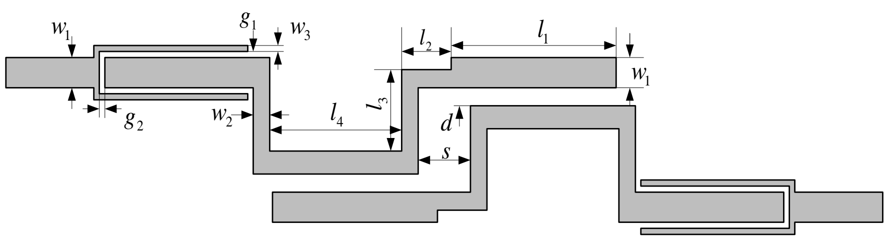
where θ_{s1} is the electrical length for the first spurious frequency at f_{s1}. From (1) and (3), we obtain:

$$\frac{f_{s1}}{f_0} = \frac{\theta_{s1}}{\theta_0} = \frac{\pi}{2\tan^{-1}(\sqrt{R_z})} \tag{4}$$

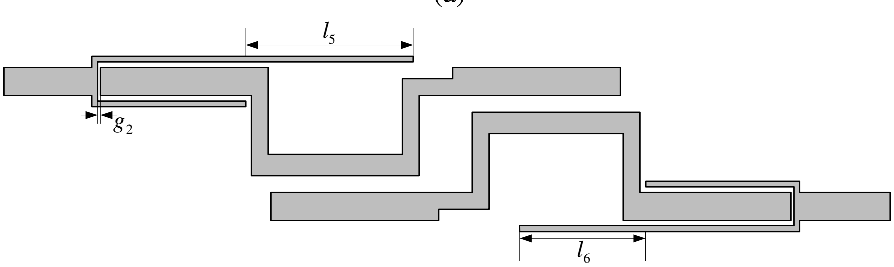
It is obtained from (4) that the harmonic frequency is only determined by R_z. In this paper, to meet the bands of 802.11b, g (2.412–1.484 GHz) [11] for lower band and the specification of 802.11a–L (5.180–5.320 GHz) [11] in WLANs, we set f_0 and f_{s1} to be 2.4/5.2 GHz, respectively.

2.1. A Dual-mode Dual-band Filter with One Transmission Zero

On the basis of the former discussion, we choose $R_z = 0.785$ with $Z_1 = 63.69\,\Omega$ and $Z_2 = 50\,\Omega$ to create two passbands at 2.4/5.2 GHz. Fig. 2(a) shows the prototype of the proposed filter, which is fabricated



(a)

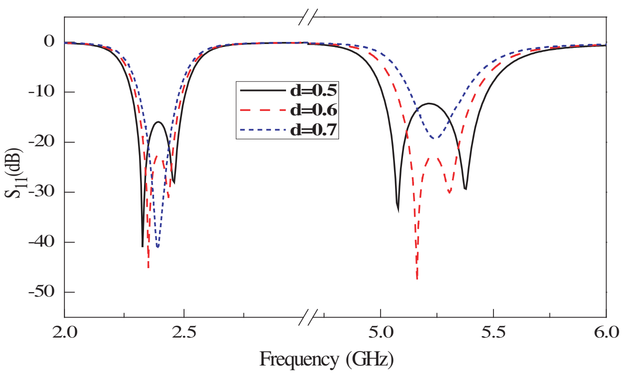


(b)

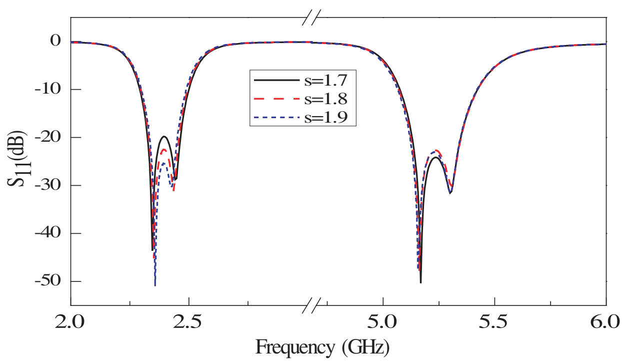
Figure 2. (a) A filter with one transmission zero. (b) A filter with four transmission zeros.

on Rogers TMM 10 with thickness of 1 mm and relative permittivity $\xi_r = 9.2$. The filter consists of two coupled SIRs and two I/O lines.

The passbands frequencies are mainly determined by the entire length of the SIRs and the ratio of characteristic impedance R_z. The gap d and distance s are turned to effectively determine the bandwidths. Fig. 3(a) shows the simulation results under different values of d. We can obtain that the bandwidths of the two bands become narrower as increasing d from 0.5 mm to 0.7 mm (all the other values are fixed) since the inter-couple degree of the SIRs becomes weaker. Fig. 3(b) shows the frequencies response under different distance s between the SIRs (all the other dimensions of the filter are unchanged). When decrease s from 1.9 mm to 1.7 mm, the bandwidth at 5.2 GHz is still hold, but the bandwidth at 2.4 becomes wider. It



(a)



(b)

Figure 3. Simulated frequency responses of the filter under different (a) gap d and (b) distance s.

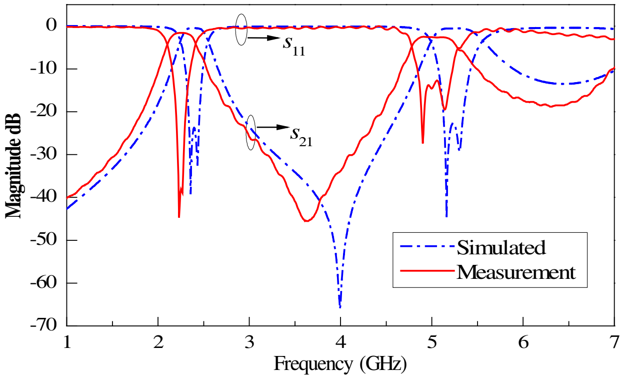


Figure 4. The response of filter with one transmission zero.

implies that d dominates the inter-couple degree in both passbands, and s only dominates the first passband.

Based on the above discussion, the structural parameters are as follows: $l_1 = 6\,\text{mm}$, $l_2 = 1.8\,\text{mm}$, $l_3 = 2.7\,\text{mm}$, $l_4 = 4.8\,\text{mm}$, $w_1 = 1\,\text{mm}$, $w_2 = 0.6\,\text{mm}$, $w_3 = 0.2\,\text{mm}$, $g_1 = g_2 = 0.2\,\text{mm}$, $d = 0.6\,\text{mm}$, $s = 1.9\,\text{mm}$. The simulation is finished by using a commercially available full-wave electromagnetic simulator. Fig. 4 shows the simulated and measured results. Both of the simulated and measured results have a good agreement except some deviation at two passbands. The measured results of filter are centered at 2.21 GHz and 5.01 GHz with bandwidths of 16.3% and 10.2%. The insertion losses of lower and upper passbands are 1.67 dB and 2.58 dB, and the return losses of both passbands are below −10 dB. A transmission zero is realized more than 45.55 dB between the passbands. The rejection level after upper band is only 18.79 dB, which influences the selectivity seriously.

2.2. A Dual-mode Dual-band Filter with Four Transmission Zeros

The above filter has one transmission zero and bad selectivity after the upper passband. If another transmission zeros can be obtained, the selectivity will be further improved. Traditionally, spur-line is an effective way to create transmission zeros [4]. In this paper, two stubs are introduced into I/O lines to get other transmission zeros. As shown in Fig. 2(b), the lengths of them are $l_5 = 6\,\text{mm}$ and $l_6 = 4.5\,\text{mm}$. The two stubs and I/O lines compose two other resonators to create transmission zeros. For boosting the coupling

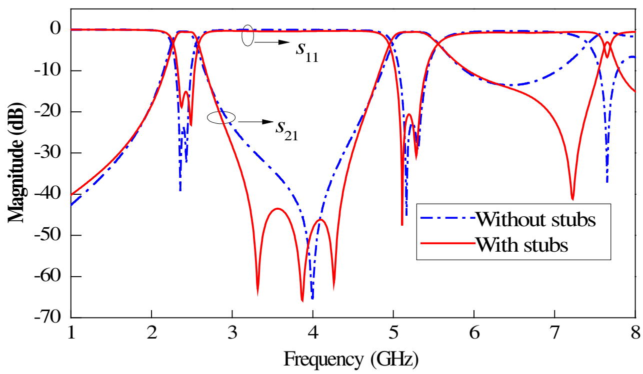
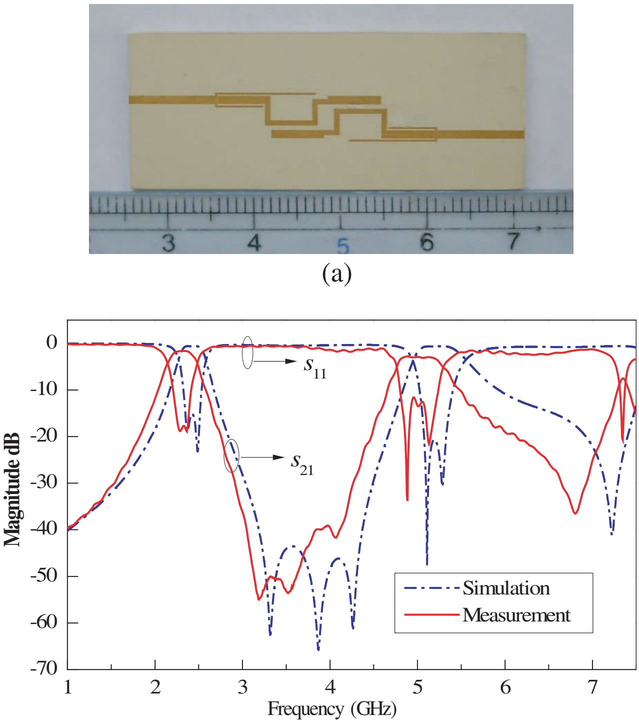


Figure 5. The response of filter with stubs and without stubs.



(a)

(b)

Figure 6. (a) Photograph of the fabricated filter. (b) Measured and simulate frequency responses of the filter.

coefficients, let $g_2 = 0.1\,\mathrm{mm}$. The simulated response is shown in Fig. 5. Compared with the filter in Section 2.1, the filter has another three transmission zeros. Transmission zeros at 3.318 GHz and 7.225 GHz are created by l_5, and transmission zero at 4.263 GHz is created by l_6. With the three transmission zeros, the selectivity has been further improved. Because of the stubs, the return losses of two bands have been affected, but both of them below -15 dB.

Figure 6(a) shows the photograph of the proposed filter. The measured frequencies response is characterized in Agilent's E5071C network analyzer. The simulated and measured results of filter with two stubs are illustrated in Fig. 6(b). The measured results of filter have two passbands centered at 2.35 GHz and 5.05 GHz with the 3-dB fractional bandwidths of 16.6% and 13.5%. The insertion losses, including the losses from SMA connector, are 1.64 dB and 2.91 dB at lower and upper passbands, and return losses are 17.7 dB and 11.6 dB in the lower and upper passbands. With the four transmission zeros located at 3.17 GHz with 55.04 dB attenuation, 3.52 GHz with 55.59 dB attenuation, 4.06 GHz with 41.65 dB attenuation and 6.80 GHz with 36.50 dB attenuation, the selectivity has been further improved. 50 MHz and 150 MHz deviation are observed at lower and upper bands, which could be attributed to material heterogeneity and fabrication tolerance in the implementation.

3. CONCLUSION

In this paper, a novel dual-mode dual-band filter with SIRs is proposed; the properties are analyzed and verified by simulation and experiment. The newly proposed filter has good passbands performance and is easy to control bandwidths. With introduced two stubs, another three transmission zeros are created, and the selectivity has been further improved. Based on the proposed filter, two filters with one and four transmission zeros have been implemented. The simulated and measured results are presented.

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