Compact dual-band bandpass filter for WLAN systems

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Abstract: A novel dual-band planar microstrip filter using parallel coupled microstrip lines and open-loop stepped-impedance resonators (SIRs) loaded with two shunt open stubs is presented. By tuning the physical lengths of open-loop SIRs, parallel coupled microstrip lines and two stubs, the bandpass filter has good dual-passband performance at 2. 55 and 5. 35 GHz and high isolation between the two passbands. The relative bandwidths of the two passbands are 11. 8% and 16. 8%, respectively. Compared with the conventional open-loop SIR filters, the designed filter has a comparatively broader fractional bandwidth at the second passband. So it can cover all the wireless LAN(local area network) bands. In addition, the filter has the features of low loss, high rejection and low ripple. The measured results are in good agreement with the simulated responses by HFSS software.

Key words: dual-band; parallel coupled microstrip lines; stepped-impedance-resonators (SIRs)

Recent development of various modern wireless communication applications has created a demand for microwave communication systems with multi-band devices. For example, the wireless local area network (WLAN) uses two frequency bands: one is the unlicensed industrial-scientific-medical (ISM) 2. 4 GHz band for IEEE 802. 11b and IEEE 802. 11g, and the other is the ISM 5. 2 GHz band for IEEE 802. 11a. Since most of the WLAN systems support at least two standards simultaneously in practical applications, such as IEEE 802. 11a and IEEE 802. 11g, dual-band bandpass filters (BPFs) have received much attention for WLAN applications in recent years. In WLAN systems, the important issues for an RF filter are simple configuration, low cost, and high performance. Many works have been done to explore advanced dual-band wireless systems, and various dual-band filters have been proposed[1-12]. To achieve dual-band BPFs, the conventional ways are 1) to use a cascade connection of a broadband bandpass filter and a bandstop filter[1]; 2) to use reduced-length parallel coupled lines[2]; and 3) to connect the main transmission line with shunt stubs and shunt serial resonators[3]. However, the aforementioned approaches increase the circuit complexity and the circuit size. There are some other ways to reduce the size of BPFs, such as using stepped-impedance resonators (SIRs) with new coupling schemes[4], using novel E-type resonators with controllable bandwidths[5], and using half-wavelength SIRs with sinuous configurations[6]. Unfortunately, there is low isolation between the two passbands. When high isolation for the two passbands is achieved, such as using hairpin resonators[7] or a ring resonator[8], the insertion loss is poor. When SIRs[9-10] and joint sharing of input and output ports of the two resonators are used[11] to achieve good performance, the bandwith of each filter at the second passband is not wide. So there is a demand to design a dual-band bandpass filter with the characteristics of compact size, high isolation loss, low insertion loss and wide band.

In this paper, on the basis of the previous work[12], we present a new configuration of a dual-band filter using two-stub-loaded open-loop SIRs and parallel coupled microstrip lines. The schematic of the proposed dual-band filter is shown in Fig. 1. The two stubs in the resonators are used to control even-mode resonant frequencies. The two parallel coupled microstrip lines are used to increase the coupling coefficient to obtain a greater bandwidth of the second passband. The filter has low insertion loss and high return loss at each passband, and high isolation between the two passbands. In addition, the features of small size, simple configuration and wide band at the second passband are also achieved. Finally a dual-band filter that covers these two ISM bands (2. 4 and 5. 2 GHz) is optimally designed and fabricated. And the measurement results show good agreement with the simulated responses by the HFSS software.

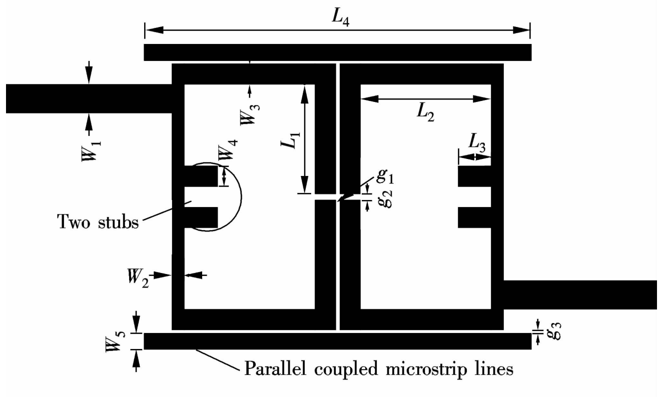

Fig. 1 Schematic of proposed dual-band microstrip bandpass filter

1 Analysis of Dual-Band Filter

First, we analyze the structure of the one-stub-loaded resonator. As can be seen from Fig. 2, it consists of one main line and an open-ended stub with different characteristic admittances Y_1 and Y_2 and electrical lengths θ_1 and θ_2. The open-ended stub is at the middle of the main microstrip line. Since the structure of the resonator is symmetric, the even-odd mode theory is adopted to analyze its characteristics.

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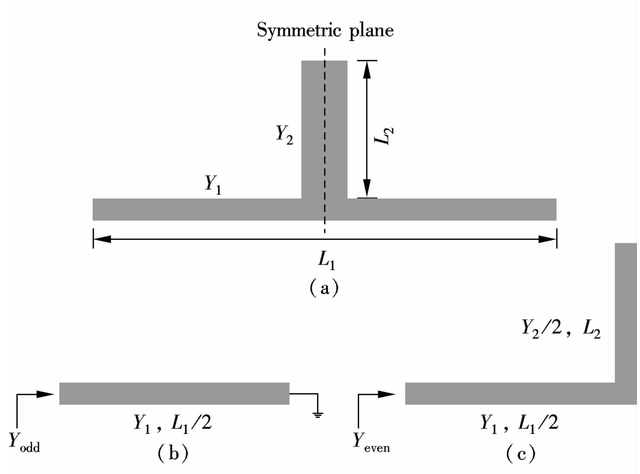

Fig. 2 One stub-loaded resonator. (a) Structure; (b) Odd-mode equivalent circuit; (c) Even-mode equivalent circuit

For odd-mode excitation, the open stub-loaded resonator can be seen as an electrical wall, where the voltage is zero, at the symmetric plane. So its input admittance can be obtained as

$$Y_{odd} = \frac{Y_1}{j\tan(\theta_1/2)} \tag{1}$$

where $\theta_1 = \beta L_1$ is the electrical length of the main microstrip line. The resonance condition is $Y_{odd} = 0$, so we can obtain the odd-mode resonant frequency,

$$f_{odd} = \frac{(2n-1)c}{2L_1\sqrt{\varepsilon_{eff}}} \tag{2}$$

where $n = 1, 2, 3$; c is the speed of light in free space; ε_{eff} is the effective dielectric constant of the medium. We can clearly see that the odd-mode resonant frequency is not influenced by the open-ended stub.

For even-mode excitation, there is no current at the centro-symmetric plane, which can be seen as an open end. So the input admittance can be obtained,

$$Y_{even} = jY_1 \frac{2Y_1\tan(\theta_1/2) + Y_2\tan\theta_2}{2Y_1 - Y_2\tan(\theta_1/2)\tan\theta_2} \tag{3}$$

where $\theta_2 = \beta L_2$ is the electrical length of the open-ended stub. Correspondingly, the resonance condition is the same as the odd-mode condition, so we can obtain the even-mode resonant frequency,

$$f_{even} = \frac{nc}{(L_1 + 2L_2)\sqrt{\varepsilon_{eff}}} \tag{4}$$

It indicates that the length of the open-ended stub L_2 has an impact on the even-mode resonant frequency.

Because the two-stub-loaded resonator has similar characteristics with the one-stub-loaded resonator and the proposed filter structure in this paper is more complex than the analytic one-stub-loaded structure, we do not theoretically analyze the two-stub-loaded SIRs. But we use the full-wave simulation tool HFSS to verify that the even-mode resonant frequencies can be flexibly controlled whereas the odd-mode resonant frequencies are fixed. First, we fix all of the variables except for the lengths of the two shunt stubs. Secondly, we change their lengths step by step to see the change in the second passband. It can be found from Fig. 3 that when the lengths L_3 of the two shunt stubs increase, the first passband is fixed whereas the second passband exhibits the trend towards a lower band.

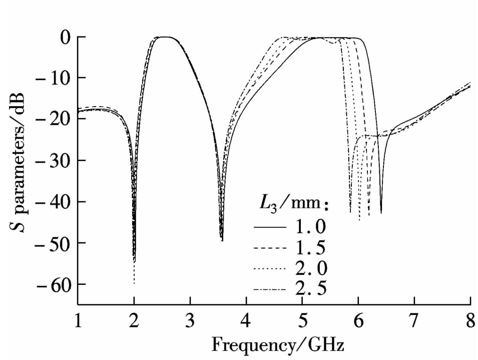

Fig. 3 Operating frequencies vs. stub length

2 Design of Dual Passband Filter

As can be seen from Fig. 1, by using the two stubs in the resonators, we can ensure that the even-mode resonant frequencies are controlled flexibly whereas the odd-mode resonant frequencies are fixed and the second passband can be more flat. By adding two parallel coupled microstrip lines, the coupling coefficient can be increased to obtain a wider bandwidth for the second passband.

The proposed dual-band filter consists of two coupled open-loop SIRs, two open stubs which extend from the middle side of each resonator, and two parallel coupled microstrip lines at the middle of the top and bottom of the resonators. The fundamental resonance frequency is related to the total length of the resonator. In order to obtain the central passband frequency, the length of the resonator is fixed. The second passband frequency can be adjusted by changing the relative position and size of the stubs and the lengths of the two coupled microstrip lines. The main function of the two parallel coupled microstrip lines is to make the bandwidth of the second passband wider by increasing the ratio of the coupling coefficient between the two open-loop SIRs. Because the second passband frequency is not twice the first passband frequency, adopting the two-stub loaded SIR structure, the BPF has more variables and becomes more flexible compared with the conventional one-stub loaded uniform-impedance resonators (UIRs). The design procedure can be divided into two steps: the first step is to determine the length and the width of the resonators with satisfactory performance in the first band, and the second step is to adjust relative dimensions toward good transmission in the second band.

According to the discussion in Ref. [12], this structure is optimized to obtain high electronic coupling between the two open-loop resonators and between the resonators and parallel coupled microstrip lines. High rejection is achieved in the forbidden bands. The dual-band filter is fabricated on a substrate of F4B with a relative dielectric constant of 2.65, a loss tangent of 0.002 and a thickness of 0.5 mm. The dimensions of the proposed filter obtained by the HFSS software are as follows: $W_1 = W_2 = 0.8$ mm, $W_4 = W_5 = 0.8$

mm, $W_3 = 0.6$ mm; $L_1 = 6.5$ mm, $L_2 = 6.0$ mm, $L_3 = 1.7$ mm, $L_4 = 18.8$ mm; $g_1 = 0.2$ mm, $g_2 = 0.3$ mm, $g_3 = 0.15$ mm.

Compared with the conventional stub-load resonators, the proposed filter has two stubs, coupled microstrip lines and a SIR structure, which means that there is no increase in the size of the normal resonators to obtain dual-band and wider bandwidth in the second passband.

3 Fabrication and Experimental Results

Fig. 4 shows a photograph of the proposed filter, and the total size of the filter is less than 32 mm × 24 mm. Moreover, the proposed filter will be smaller if it is applied in the circuit. The proposed filter has attractive features, including dual-band applications, small size, adjustable second passband and a comparatively broader band compared with the conventional microstrip square open-loop filters. So the proposed dual-band bandpass filter is suitable for WLAN applications.

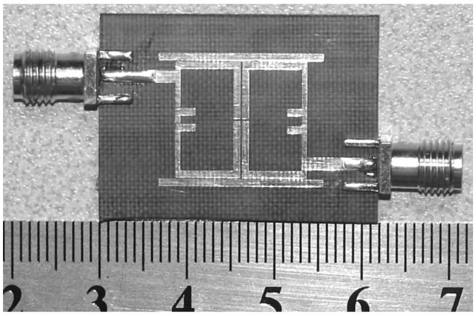

Fig. 4 Photograph of the fabricated dual-band microstrip bandpass filter

Simulation is performed by the HFSS software. Measurements are tested from 1 to 7 GHz with an E5230A vector network analyzer. Fig. 5 shows the measured *S* parameters and the full-wave simulation results from HFSS 11. We can clearly see that the measurements agree with the simulation in general with no modifications in the layout. The basic parameters are shown in Tab. 1. It can also be seen that the experimental results are in good agreement with the simulation results. We believe that there is a possibility to make the dual-band filter cover all the WLAN frequency bands due to the wider second passband.

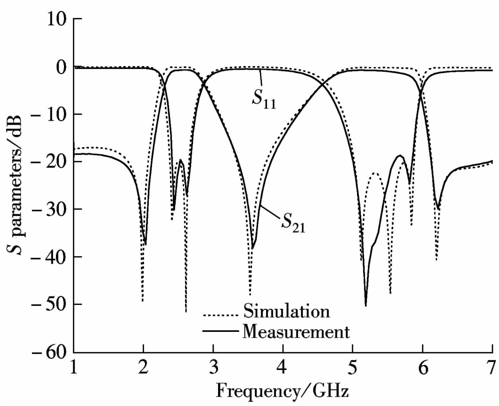

Fig. 5 Comparison of simulated and measured results of the proposed dual-band bandpass filter

Tab. 1 Measured and simulated parameters of the dual-band bandpass filter at 2.55 and 5.35 GHz

Dual-band filter	Bandwidth/%		Insertion loss/dB		Return loss/dB	
	First band	Second band	First band	Second band	First band	Second band
Simulation	12.7	17.3	0.13	0.2	21.7	22.6
Measurement	11.8	16.8	1.17	0.85	19.8	35.6

In addition, the proposed dual-band filter can generate transmission zeros and provide a better cutoff rate in the stopband. The two measured transmission zeros of the first stopband are −37.43 dB at 2.04 GHz and −38.18 dB at 3.57 GHz, and the transmission zeros of the second stopband are −38.18 dB at 3.57 GHz and −29.94 dB at 6.22 GHz. We can see that they share the same transmission zero at 3.47 GHz. So good selectivity is achieved in the lower band whereas some defect exists in the higher band. It is necessary to introduce another transmission zero at the high passband to realize better selective performance. The existence of insertion loss is mainly due to both the conductor and the dielectric loss of circuit. The slight difference between the simulation results and the measurement results may be due to fabrication errors or the variations of material properties. It can be improved by more careful fabrication and measurement.

4 Conclusion

In this paper, a novel configuration comprised of parallel coupled microstrip lines and open-loop SIRs loaded with two shunt open stubs is presented to design a dual-band planar bandpass filter, which has good frequency responses at 2.55 and 5.35 GHz. By a simple theoretical analysis, we obtain the properties of the dual-band filter by simulation and measurement. Using the simple compact configuration, the proposed dual-band filter has significantly miniaturized the overall size, and achieved good dual-passband filtering performances at the two specified bands. The dual-band BPF has low insertion loss and high return loss at each passband, and high isolation between two passbands. The measurement results are found to be in good agreement with the simulation results.

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用于无线局域网的小型化双频段带通滤波器

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摘要:提出了一个新型的平面微带双频段带通滤波器,由加载双分支线的开环阶梯阻抗谐振器和平行耦合微带线组成.通过调节开环阶梯阻抗谐振器、平行耦合微带线和加载分支线的长度,带通滤波器在2.55与5.35 GHz具有很好的双通带特性且在其间有很好的隔离度.两者的相对带宽分别为11.8%与16.8%.与传统的开环阶梯阻抗谐振器相比,该带通滤波器在第2频带有更宽的带宽,可以覆盖WLAN在高频段的整个范围.该双频段带通滤波器具有低损耗、高隔离、低纹波的特性.通过比较HFSS软件的仿真结果与实际测得的结果发现,两者具有很好的一致性.

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