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A HIGH SELECTIVITY QUADRUPLE-MODE BPF WITH TWO SHORT-CIRCUITED STUB-LOADED SIRS

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Abstract—In this paper, a high selectivity quadruple-mode bandpass filter (BPF) with source-load coupling is proposed. This filter uses two short-circuited stub-loaded stepped-impedance resonators (SIRs) which have the same type but different size. Two SIRs can generate four operating modes, which can be approximately adjusted individually. Owing to the special design of the filter, the coupling of two resonators is weak. In each resonator, the even-mode frequency can be flexibly controlled by changing the length of the short stub, whereas the odd-mode one remains stationary. Due to the source-load coupling, two transmission zeros are close to the cut-off frequencies of the passband, which leads to high selectivity. Simulated results show that central frequency is 2.27 GHz with 3-dB fractional bandwidth of 22.9%. The measured and simulated results are well complied with each other.

1. INTRODUCTION

Recently, broadband BPFs with low loss, sharp transition, and compact size are highly desirable for wireless communication systems. To realize them, there are two typical methods: using cascading lowpass filters (LPFs) and highpass filters (HPFs) [1–4] or multiple-mode resonators [5–7]. The first method is cascading LPFs and HPFs, where LPFs take care of the upper stopband suppression and HPFs deal with the lower one. This method is effective, but a defected ground structure [1, 2] is required whose fabrication process is complicated and difficult to integrate with other microwave devices. The second

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method is utilizing a triple-mode or a quadruple-mode resonator to design the broadband filters. Furthermore, they also have improved the upper stopband suppression by introducing transmission zeros [5, 6] or utilizing a EBG structure and coupled lines with suppressed ability at higher-order mode [7]. However, the lower stopband suppression is also important to the higher one. A cross-coupling structure which is between the input and output lines, together with E-shaped microstrip stepped-impedance resonator (SIR), are applied to design a dual-wideband bandpass filter [8], whose frequency response characteristics exhibit sharp roll-off that the edge performance of the passband and stopband could be improved. The SIR has become very popular in the design of dual-band filters as it has a dual passband behavior that can easily control the second passband frequency, which is compact in size and has established design equations [9–13]. Most of the work has focused mainly on the dual-band filter.

In this paper, a quadruple-mode broadband BPF with two short-circuited stub-loaded stepped-impedance resonators (SIRs) and input/output source-load coupling feed structure is presented. The proprosed BPF has a good performance on high selectivity which includes lower and upper stopband suppression. As shown in Fig. 1, a short-circuited stub-loaded SIRs is utilized to make the odd-mode of the SIR close to the even-mode which can be used to expand bandwidth of the proposed filter. Due to parallel coupled-line and folded short-circuited stub-loaded SIRs, two transmission zeros are created in both sides of the passband. Furthermore, the source and load are connected to two short-circuited stub-loaded SIRs. Two transmission zeros can be conveniently controlled by tuning the length of the L_5. A high selectivity quadruple-mode quasi-elliptic BPF is simulated, fabricated and measured. Simulations and measurements show excellent agreement.

2. FILTER DESIGN

The proposed short-circuited stub-loaded SIR is formed by adding two identical short stubs to the conventional SIR as illustrated in Fig. 1(a). Since the resonator is symmetrical to the centre plane, the odd-even-mode method can be implemented [14]. The approximate transmission line circuit models are represented in Figs. 1(c) and (d). θ_1, θ_2, θ_3, θ_4 are electrical lengths of four sections with lengths l_{11}, l_{12}, l_{13}, l_{14}, respectively. Y_1, Y_2, Y_3, Y_4 are characteristic admittances of the widths w_1, w_2, w_3, w_4.

For simplicity, $Y_2 = Y_3 = Y_3$ are assumed, the input admittance

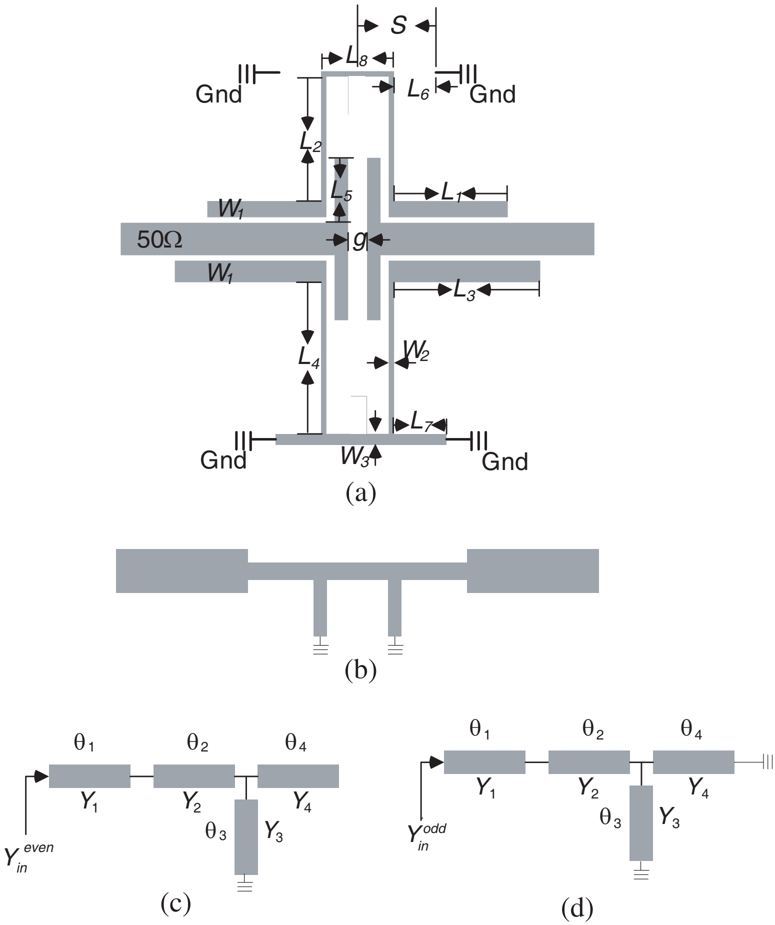

Figure 1. (a) Schematic of the quadruple-mode broadband BPF with source-load coupling. (b) Structure of the short-circuited stub-loaded SIR. (c) Even-mode equivalent circuit. (d) Odd-mode equivalent circuit.

Y_{in}^{even} of the even mode resonator in Fig. 1(c) can be expressed as:

$$Y_{in}^{even} = Y_1 \frac{jY_2 \frac{(\tan\theta_4 - 1/\tan\theta_3) + \tan\theta_2}{1 - (\tan\theta_4 - 1/\tan\theta_3)\tan\theta_2} + jY_1 \tan\theta_1}{Y_1 - Y_2 \frac{(\tan\theta_4 - 1/\tan\theta_3) + \tan\theta_2}{1 - (\tan\theta_4 - 1/\tan\theta_3)\tan\theta_2} \tan\theta_1} \tag{1}$$

When electrical length θ_3 of the two identical short-circuited stubs which are attached to the center plane nearby is very small, $|1/\tan\theta_3|$ is far greater than $|\tan\theta_4|$ in the lower frequency. The formula (1) can be approximately expressed as:

$$Y_{in}^{even} \approx jY_1 \frac{-Y_2 + Y_1 \tan\theta_1 \tan(\theta_2+\theta_3)}{Y_1 \tan(\theta_2+\theta_3) + Y_2 \tan\theta_1} \tag{2}$$

From the condition $Y_{in}^{even} = 0$, the fundamental resonant frequencies of the even-mode excitation can be extracted as:

$$\tan\theta_1 \tan(\theta_2+\theta_3) = Y_2/Y_1 \tag{3}$$

It can be observed from the formula (3) that resonant frequencies of even-mode excitation are exclusively correlated to the short-circuited stub.

Similarly, the fundamental resonant frequencies of the odd-mode excitation in Fig. 1(d) can be extracted as:

$$Y_{in}^{odd} = \frac{Y_2 \frac{-j(\tan\theta_3+\tan\theta_4-\tan\theta_2\tan\theta_3\tan\theta_4)}{\tan\theta_3\tan\theta_4+\tan\theta_2\tan\theta_3+\tan\theta_4)} + jY_1\tan\theta_1}{Y_1 + jY_2 \frac{-j(\tan\theta_3+\tan\theta_4-\tan\theta_2\tan\theta_3\tan\theta_4)}{\tan\theta_3\tan\theta_4+\tan\theta_2(\tan\theta_3+\tan\theta_4)}\tan\theta_1} \tag{4}$$

From the condition $Y_{in}^{odd} = 0$, the fundamental resonant frequencies of the odd-mode excitation can be extracted as:

$$\frac{\tan\theta_1\tan\theta_2\tan\theta_3+\tan\theta_1\tan\theta_2\tan\theta_4+\tan\theta_1\tan\theta_3\tan\theta_4}{\tan\theta_3+\tan\theta_4-\tan\theta_2\tan\theta_3\tan\theta_4} = Y_2/Y_1 \tag{5}$$

When two identical short-circuited stubs whose electrical length θ_3 and θ_4 is very small are attached to the center plane nearby, $|\tan\theta_3|$ and $|\tan\theta_4|$ are far greater than $|\tan\theta_3\tan\theta_4|$ in the low frequency. The formula (5) can be approximately expressed as:

$$\tan\theta_1\tan\theta_2 \approx Y_2/Y_1 \tag{6}$$

It can be observed from the formula (6) that the resonant frequencies of odd-mode excitation are exclusively not correlated to the short-circuited stub-loaded. The approximate fundamental resonant frequencies of the even and odd mode resonators can be calculated by formula (3) and (6), respectively. Four modes will be excited by two different sizes of this type of resonators. Assuming that the fundamental odd-mode resonant frequencies of the two SIRs with different size are f_{m2} and f_{m4}, even-mode ones are f_{m1} and f_{m3}, respectively. Thus, the f_{m2} and f_{m4} can be allocated in the desired band by reasonable designing the SIR, the f_{m1} and f_{m3} can be adjusted by varying the parameters of the short stubs.

Herein, we choose the dimensions of the resonators: $L_1 = 6.7\,\text{mm}$, $L_2 = 9.8\,\text{mm}$, $L_3 = 10\,\text{mm}$, $L_4 = 8.6\,\text{mm}$, $L_6 = 2.4\,\text{mm}$, $L_7 = 2.1\,\text{mm}$ and $L_8 = 4.7\,\text{mm}$. The four resonant frequencies are calculated: $f_{m1} = 2.26\,\text{GHz}$, $f_{m2} = 2.38\,\text{GHz}$, $f_{m3} = 2.49\,\text{GHz}$ and $f_{m4} = 2.62\,\text{GHz}$,

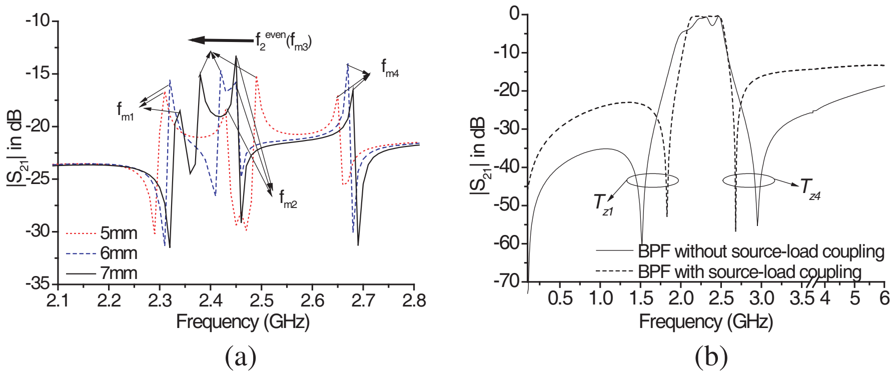

Figure 2. Simulated frequency-dependent transmission response of the presented BPF (a) Varying short-circuited stub-loaded S ($L6 + L8/2$). (b) The quadruple-mode broadband BPF with and without source-load coupling.

respectively. The frequency-dependent transmission responses are simulated in the case of weak coupling in Fig. 2(a) and Fig. 2(b) with $|S_{21}|$. By tuning the length of short stubs, the even-mode resonant frequencies (f_{m1}, f_{m3}) merely controlled, whereas the odd-mode ones (f_{m2}, f_{m4}) remain stationary. The short stubs can be applied to push even-mode into the desired passband [15]. When S ($L_6 + L_8/2$) is selected as follows: 5 mm, 6 mm and 7 mm, the f_{m3} moves towards the lower frequency, whereas the resonant frequencies (f_{m1}, f_{m2}, f_{m4}) hardly changed. In other words, when θ_1 and θ_2 remain stationary, varying θ_3 can control the even-mode frequencies. Formula (3) are complied well with simulated results as shown in Fig. 2(a). Similarly, the fundamental resonant frequencies of the odd-mode can be adjusted by tuning θ_1 and θ_2 corresponding to formula (6).

When the resonators are properly fed with increased coupling level [16], the four resonant modes can be used to make up of a broadband BPF. As shown in Fig. 2(b), the simulated $|S_{21}|$ of the broadband BPFs with and without source-load coupling are simulated by HFSS. It can be found that two transmission zeros T_{z1} and T_{z4} as with source-load coupling are closer to the passband as illustrated in Fig. 2(b).

Consequently, a high selectivity quadruple-mode quasi-elliptic BPF can be obtained. As shown in Fig. 1, the optimized parameters of the proposed filter are shown in Table 1.

The filter is fabricated on a thin dielectric substrate with a low relative permittivity of 2.2, a loss $\tan\delta$ of 0.0009 and a thickness

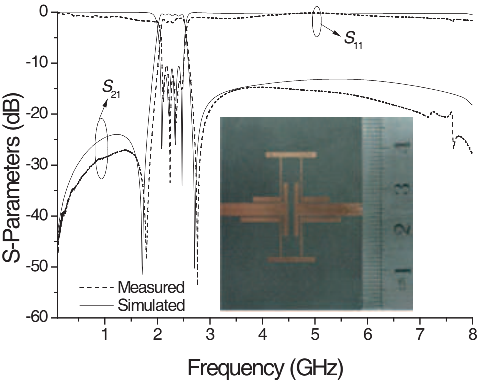

Figure 3. Simulated and measured frequency responses of the broadband quasi-elliptic BPF with source-load coupling.

Table 1. Dimensions of the proposed filter (UNIT: mm).

Parameters of the proposed filter							
L_1	6.7	L_4	8.6	L_7	2.1	W_2	0.34
L_2	9.8	L_5	5	L_8	4.7	W_3	1.2
L_3	10	L_6	2.4	W_1	1.2		

of 1 mm. The 50 ohm feed line is terminated with a standard SMA connector to facilitate the measurement and connect with other standard microwave modules.

3. RESULTS AND DISCUSSION

The filter with source-load coupling is fabricated on the RT/Duroid 5880 substrate and its photograph is shown in Fig. 3. The filter performance is measured by Agilent network analyzer N5230A. Simulated results show that the central frequency is 2.27 GHz with 3-dB fractional bandwidth of 22.90%. The measured 3-dB passband is in the range of 2.08–2.53 GHz and input return loss ($|S_{11}|$ in dB) is less than -11 dB. Two transmission zeros near the cut-off frequency are located at 1.79 GHz and 2.76 GHz resulting in sharp skirt, with an attenuation level of less than -48 dB. In addition, Fig. 3 shows the measured wideband response of the developed filter. The stopband rejection is better than 15.2 dB up to 8 GHz. The measured and simulated results are well complied with each other.

4. CONCLUSION

The application of inductive source-load coupling in microstrip quadruple-mode filter design has been studied intensively. It revealed that a high selectivity quasi-elliptic response with two transmission zeros at both skirts can be obtained easily. The filter prototype with the fractional bandwidth of 22.9% is fabricated to demonstrate the predicted performances in experiment.

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