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INVESTIGATION OF DUAL-BAND BALUN BANDPASS FILTERS BASED ON COUPLED RING RESONATORS

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Abstract—An investigation of dual-band balanced-to-unbalanced (blaun) bandpass filters (BPFs) is presented in this letter. Two types of balun BPFs named Type-A and Type-B filters based on coupled ring resonators are discussed and fabricated. Both the simulated and measured results show that these balun-BPFs have not only good amplitude performances but also excellent phase difference performances. The center frequencies of these balun BPFs are set at 2.4 GHz/5.6 GHz for Type-A and 1.57/4.65 GHz for Type-B balun filters. The differences are $180^{\circ} \pm 5^{\circ}$ in phase and within 0.6 dB in magnitude of type A and 0.73 dB of type B, respectively. Thus, these balun BPFs can be used in many wireless communication systems.

1. INTRODUCTION

As two key components, both balun and filter play important roles in the design of radio frequency (RF) front-end modules. Some structures for balun design were discussed [1–5]. In order to satisfy the high requirements of easy integration, compact size, and low cost, an idea of integrating both balun and bandpass filter (BPF) together has been proposed to reduce the loss and circuit size [6–13]. This means that an integrated device can provide not only a frequency-band selection as a filter, but also a balanced-to-unbalanced conversion as a balun. A design of balun BPF in the low temperature co-fire ceramic (LTCC) technology was presented in [6] while dual mode ring resonators were used to fabricate balun BPFs in [7, 8]. In [9], a single cross-slotted patch resonator was achieved by using the hybrid structure which

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contains microstrip and co-planar waveguide (CPW) resonators in [10]. A tunable balun with bandpass responses by loading capacitors was proposed in [11]. In [12], a single band balun BPF using a single coupled ring resonator was discussed.

In the previous studies, the authors have presented a balun BPF with simple structure and good performances based on coupled ring resonator [12]. However, the reported balun BPF has only one passband. In this letter, two types of dual-band balun BPFs named Type-A and Type-B are presented and discussed. In the proposed dual-band balun BPFs, two frequency channels are integrated into one function block, so it can reduce the size and cost of a wireless communication system. Both these two balun BPFs are fabricated based on coupled ring resonators, the simulated and measured results show that these balun BPFs can provide good imbalanced performances both in phase and in magnitude. The differences between the two outputs are $180° \pm 5°$ in phase and within 0.6 dB in magnitude for type A and 0.73 dB for type B, respectively. The theoretical design, simulation, and experimental results are given and discussed in this letter.

2. DUAL-BAND BALUN-BPFS DESIGN

2.1. Type A: Single Resonator with Stubs Loaded

As depicted in Figure 1, a dual-band balun BPF using a single coupled ring resonator and loaded stubs is proposed. Design of a planar filter using single coupled sing resonator with symmetric and skew-

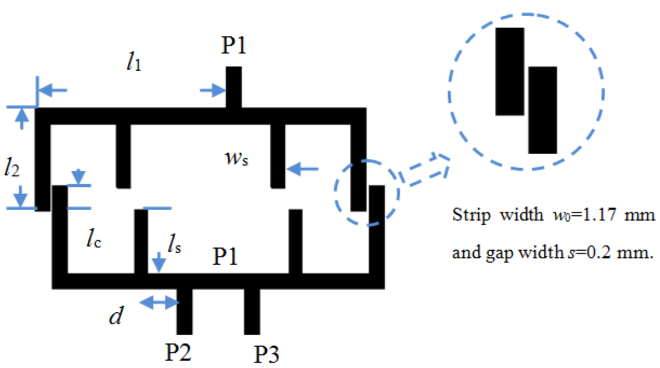

Figure 1. Configuration of the proposed type-A dual-band balun-BPF.

symmetric feedings was discussed in [12, 13] as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} -1 & j\frac{\cos^2\theta_1}{2wC} \\ 0 & -1 \end{bmatrix} \tag{1a}$$

$$S_{31} = \frac{-1}{2 - j\cos^2\theta_1/2wCZ_L} \tag{1b}$$

$$\begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} = \begin{bmatrix} 1 & -j\frac{\cos^2\theta_1}{2wC} \\ 0 & 1 \end{bmatrix} \tag{2a}$$

$$S_{21} = \frac{1}{2 - j\cos^2\theta_1/2wCZ_L}. \tag{2b}$$

To meet the demands of multiple frequencies communication systems, a second pass band with both filtering and difference performances is designed in this letter.

Open-circuited loaded stubs are used regularly to improve the filter characteristics, and to generate a second passband. Figure 2 shows the frequency response of this dual-band balun BPF with different loaded stubs length of l_s. It is seen that the center frequency f_1 of the first passband (at about 2.4 GHz) remains almost unvaried while the center frequency f_2 of the second passband (at about 5.6 GHz) increases as l_s decreased while the fist passband f_1 can be controlled by adjusting the length of the entire coupled ring resonator, as shown in (1a)–(2b).

Thus, a dual-band balun BPF is obtained, and both the dual center frequencies can be controlled by adjusting the circumference

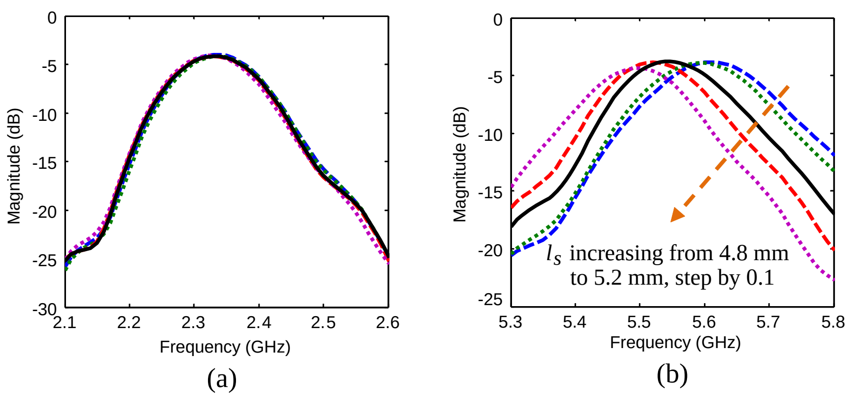

Figure 2. Frequency responses of (a) the first passband and (b) the second passband with different length of l_s.

of entire coupled ring resonator and the length or loaded location of the open-circuited stubs, severally. The dimensions of this kind of balun BPF can be determined by two steps. First, the dimensions of coupled ring resonator can be fixed with f_1 [12]. Second, the location and dimensions of the loaded stubs can be determined by the second passband f_2 as above analyzed. By the way, the bandwidth of the dual passbands can be controlled by tuning the coupled strength of the coupled ring resonator and the characteristic impedance of the loaded stubs, respectively.

2.2. Type B: Multiple Coupled Ring Resonators

Nowadays, more and more communication systems need compact passive circuits with wide passband or multi-passband. In this case, a balun BPF with dual-passband is excited by loaded multiple coupled ring resonators in this work. Both of the center frequencies are tunable, and the first frequency is centered at 1.57 GHz for globe position system (GPS) while the second passband is set at about 4.65 GHz for microwave radio relay communication (MRRC), as shown in Figure 3.

Multiple coupled ring resonators have been used in this type of dual-band balun BPF. As shown above, the first passband can be controlled by adjusting the circumference of the largest coupled ring resonator. To excite a second passband and to improve the filtering performance, other three coupled ring resonators are loaded. Similarly, the center frequency of second passband which is excited by these loaded resonators can be adjusted by changing the circumference of these three resonators. Both these dual resonate frequencies can be tuned independently with each other. Similarly, the bandwidth of the first and second passband of this dual-band balun BPF can be controlled by the coupled strength of the largest coupled ring resonator

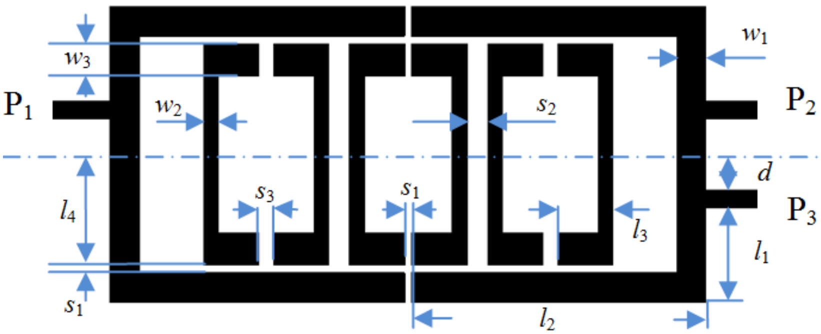

Figure 3. Configuration of proposed type-B dual-band balun BPF.

and the loaded other three coupled ring resonators. The bandwidth will be larger when the coupled strength is stronger.

For demonstration, both these two types of dual-band balun BPFs are fabricated on a substrate with dielectric constant of 3.38, loss tangent of 0.0027, and thickness of 0.508 mm. Tables 1 and 2 provide the definite dimensions of each balun BPF, respectively.

Table 1. Physical parameters for type A. Unit: mm.

w_0	w_s	l_1	l_2	l_c	l_s	d	s
1.2	1.0	14.8	8.0	2.0	5.0	3.2	0.2

Table 2. Physical parameters for type B. Unit: mm.

w_1	w_2	w_3	l_1	l_2	l_3	l_4	d	s_1	s_2	s_3
2.0	1.0	2.2	6.4	20	3.9	7.9	2.4	0.1	0.8	1.0

3. RESULTS AND DISCUSSION

Based on the analysis in previous section, both type A and type B balun BPFs are designed and fabricated on RO4003, as shown in Figure 4.

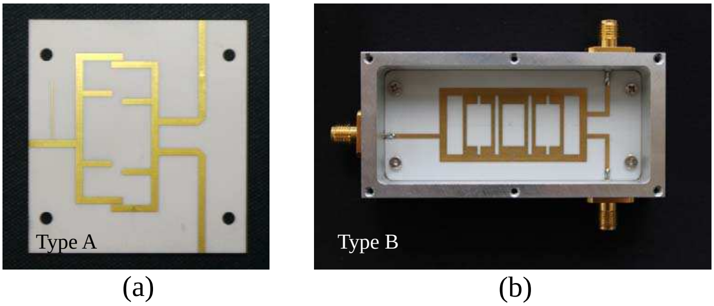

Figure 4. Photos of proposed balun BPFs. (a) Type A and (b) type B.

Figure 5 shows the measured frequency responses of proposed balun BPFs. At the operating frequencies, the insertion losses are less than $(3 + 4)$ dB for type A and less than $(3 + 2)$ dB for type B while all the return losses are better than -10 dB.

Figure 6 depicts the measured amplitude imbalances and phase differences of type A and type B balun BPFs, and the specific

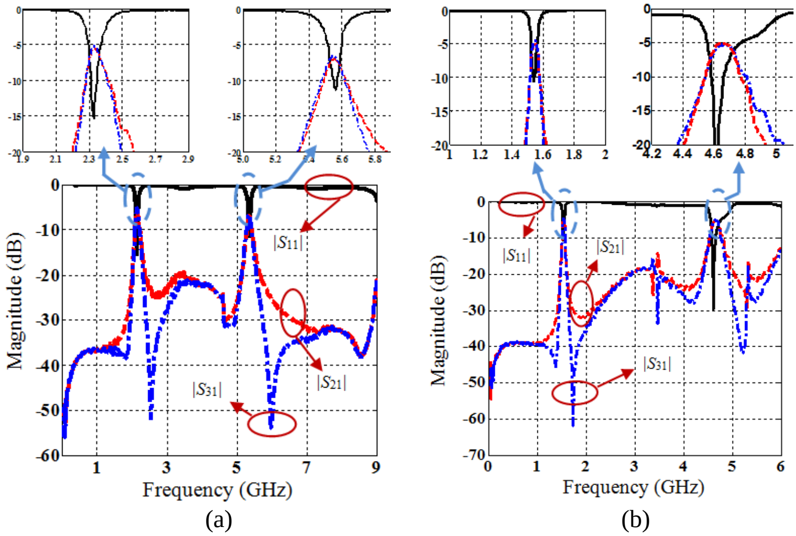

Figure 5. Frequency responses of (a) type A and (b) type B balun BPFs.

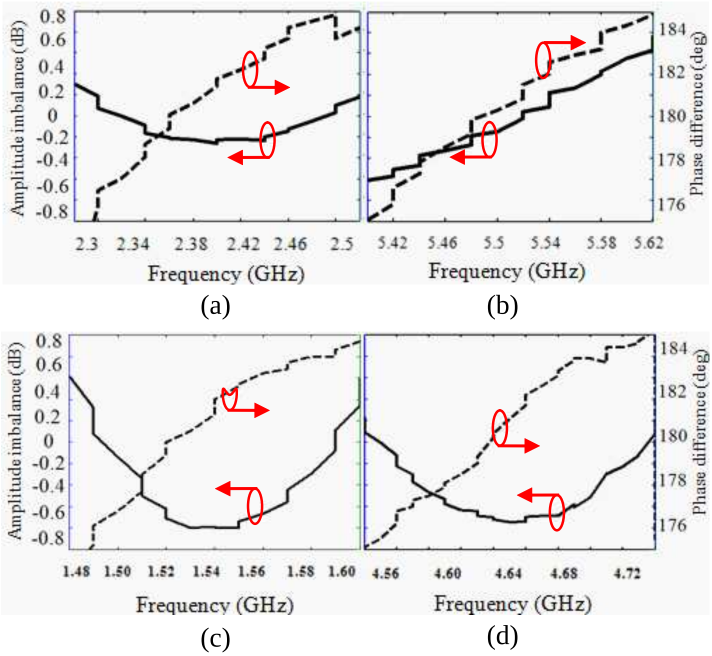

Figure 6. Measured amplitude imbalance and phase difference of (a) first passband of type A, (b) second passband of type A, (c) first passband of type B, and (d) second passband of type B balun BPFs.

Table 3. Difference characteristics and fabricated size.

Passband	Amplitude imbalance (dB)	Phase difference (degree)	Physical size (mm × mm)	Electrical size
A1	0.28	180 ± 5	25×14	$0.32\lambda_1 \times 0.18\lambda_1$
A2	0.60	180 ± 5		
B1	0.73	180 ± 5	20×40	$0.17\lambda_2 \times 0.33\lambda_2$
B2	0.68	180 ± 5		

A1 and A2: the first and second passband of type A balun BPF; B1 and B2: the first and second passband of type B balun BPF; λ_1 and λ_2: guided wavelength of the microstrip at 2.4 GHz and 1.57 GHz, respectively.

characteristics are shown in Table 3. Good amplitude imbalance and phase difference are obtained.

4. CONCLUSION

Dual-band balun BPFs are presented in this letter. The proposed balun BPFs are very compact with good imbalance characteristics. The differences are $180° \pm 5°$ in phase and within 0.6 dB in magnitude of type A and 0.73 dB of type B, respectively. Thus, these balun BPFs are good candidates in the applications of RF/MW/mm-wave communication systems.

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