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A HIGH PERFORMANCE BALUN BANDPASS FILTER WITH VERY SIMPLE STRUCTURE

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Abstract—A high performance balun bandpass filter (BPF) with very simple structure is proposed in this letter, this structure realizes superior performance in bandpass filtering meanwhile with good differential performance of the balun. The proper balanced outputs and BPF characteristic by the symmetric feeding and skew-symmetric feeding have been obtained, and the theory of this simple structure for unbalanced input to balanced outputs has been studied. The center frequency of the fabricated balun-BPF was operated at 2.4 GHz with 5.8% fractional bandwidth (FBW), and this frequency is used for Bluetooth and some other communication systems. The differences between the two outputs are $180° \pm 5°$ in phase and within 0.39 dB in magnitude. At f_0, the amplitude imbalanced and phase difference are within 0.37 dB and 179.2°, respectively. The measured frequency responses agree well with the simulated ones. With the theoretical analyses and practical results, it is shown that the proposed one has the advantages of simple structure, convenient analysis and good performance of both BPF and balun.

1. INTRODUCTION

Most modern microwave communication systems require balanced components as well as unbalanced structures in order to reduce the noise and higher-order harmonics and improve the dynamic range of the systems. In radio frequency (RF) and microwave communication systems, many circuits require a balun with balanced components, which is frequently connected to a BPF to achieve noise, high-order harmonics or unbalanced current reduction. Hence an idea of integrating these two devices has been proposed to reduce the cost

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and circuit size [1–8]. In [1–3], dual-mode ring resonators with three ports are used to realize compact balun filter. Two types of stepped impedance resonators are presented in [4, 5] to design balanced-to-unbalanced bandpass filters. In [6], a single cross-slotted patch resonator is employed in a dual-mode balun bandpass filter to achieve compact size and low insertion loss. The design of compact balanced-to-unbalanced bandpass filters in the low temperature co-fired ceramic (LTCC) technology is presented in [7] while hybrid resonator with series and shunt resonances are used in filters and balun filters in [8].

With increasing demands of ever smaller circuitry dimension, the miniaturization for distributed balun-BPF is necessary, especially at low gigahertz frequency regime. In this letter, a balun-BPF with simple structure is presented. Compared with the existing balun-filters, the proposed balun-BPF has shown simpler construction, better size reduction and easier fabrication. At the same time, it also provides good balanced outputs in phase and magnitude. The differences between the two outputs are $180^\circ \pm 5^\circ$ in phase and within 0.39 dB in magnitude. At f_0, the amplitude imbalanced and phase difference are within 0.37 dB and 179.2°, respectively. The theoretical design, simulation, and experimental results are given and discussed, which show good agreement with each other.

2. THEORY AND NETWORK EQUIVALENCE

Multiple coupled lines have been studied and used in filter design [9, 10]. Figs. 1(a) and (b) show the conventional multiple coupled lines and the capacitively loaded multiple coupled lines. Fig. 1(c) presents the equivalent circuit of a conventional two coupled lines resonator for discussion. The resonator is fed by symmetric feedings (i) and (ii), andor skew symmetric feedings (i) and (iii).

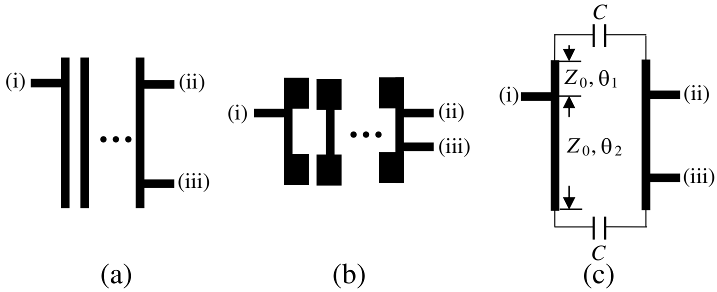

Figure 1. (a) Conventional straight and (b) capacitively loaded coupled resonators and (c) the equivalent circuit of a conventional two coupled lines resonator.

As the resonator shown in Fig. 1(c) is fed by skew symmetric feedings (i) and (iii) (port (ii) is matched with $50\,\Omega$), the transmission metrics of lower and upper paths can be found in (1) and (2).

$$\begin{bmatrix} A_l & B_l \\ C_l & D_l \end{bmatrix} = \begin{bmatrix} \cos(\theta_1+\theta_2)+\frac{1}{wZ_0C}\cos\theta_1\sin\theta_2 & jZ_0\sin(\theta_1+\theta_2)-j\dfrac{\cos\theta_1\cos\theta_2}{wC} \\ j\frac{1}{Z_0}\sin(\theta_1+\theta_2)+j\frac{1}{wZ_0^2C}\sin\theta_1\sin\theta_2 & \cos(\theta_1+\theta_2)+\frac{1}{wZ_0C}\sin\theta_1\cos\theta_2 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} A_u & B_u \\ C_u & D_u \end{bmatrix} = \begin{bmatrix} \cos(\theta_1+\theta_2)+\frac{1}{wZ_0C}\sin\theta_1\cos\theta_2 & jZ_0\sin(\theta_1+\theta_2)-j\dfrac{\cos\theta_1\cos\theta_2}{wC} \\ j\frac{1}{Z_0}\sin(\theta_1+\theta_2)+j\frac{1}{wZ_0^2C}\sin\theta_1\sin\theta_2 & \cos(\theta_1+\theta_2)+\frac{1}{wZ_0C}\cos\theta_1\sin\theta_2 \end{bmatrix} \quad (2)$$

With the aid of circuit theory, the transmission matrix of the whole circuit can be written as (3) [11].

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \dfrac{A_uB_l+A_lB_u}{B_u+B_l} & \dfrac{B_uB_l}{B_u+B_l} \\ \dfrac{(A_uB_l+A_lB_u)(B_uD_l+B_lD_u)-(B_u+B_l)^2}{(B_u+B_l)B_uB_l} & \dfrac{B_uD_l+B_lD_u}{B_u+B_l} \end{bmatrix} = \begin{bmatrix} \dfrac{A_u+A_l}{2} & \dfrac{B_u}{2} \\ \dfrac{(A_u+A_l)^2-4}{2B_u} & \dfrac{A_u+A_l}{2} \end{bmatrix} \quad (3)$$

In the passband, when $\theta_1+\theta_2=\pi$ the transmission matrix can be calculated from (3) as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} -1 & j\dfrac{\cos^2\theta_1}{2wC} \\ 0 & -1 \end{bmatrix} \quad (4)$$

so, the transmission coefficient can then be found as

$$S_{31} = \frac{-1}{2-j\cos^2\theta_1/2wCZ_L} \quad (5)$$

where the parameter Z_L is the system impedance ($50\,\Omega$).

Similar analysis could be applied to the symmetric feedings (i) and (ii). The transmission matrix of the symmetric feed structure is expressed as

$$\begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} = \begin{bmatrix} 1 & -j\dfrac{\cos^2\theta_1}{2wC} \\ 0 & 1 \end{bmatrix}. \quad (6)$$

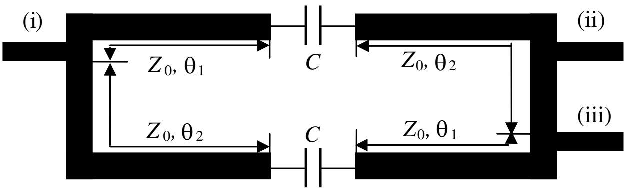

Figure 2. Equivalent circuit of the proposed resonator.

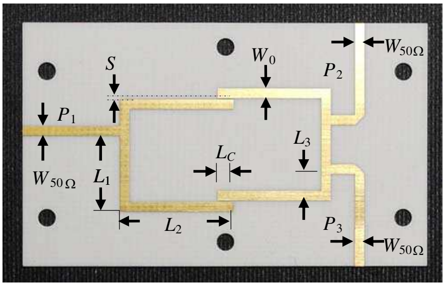

Figure 3. Photograph and its parameters for the proposed balun-BPF (W_0 = 1.17 mm, S = 0.2 mm, L_1 = 9.3 mm, L_2 = 14 mm, L_3 = 3.3 mm, and L_C = 2 mm).

The transmission coefficient of symmetric is found as

$$S_{21} = \frac{1}{2 - j\cos^2\theta/2wCZ_L} \tag{7}$$

which is the negative of the one of skew symmetric fed S_{31}. Therefore, it can be seen that feed ports (ii) and (iii) have the same magnitude and the phase difference is 180° in the passband. Thus, a balun-BPF can be designed by this simple structure.

3. BALUN-BPF DESIGN

Based on above analysis, a balun-BPF is fabricated. Fig. 2 shows the equivalent circuit of the proposed balun-BPF, which consists of two half-wavelength transmission-line resonators which are arranged as a ring with two gaps. The resonator is fed by symmetric feedings (i) and (ii), or skew symmetric feedings (i) and (iii).

In order to increase the coupling coefficient, coupled-lines structures were used for this balun-BPF design, as shown in Fig. 3. It should be noted that the circular bends at ports 2 and 3 are added

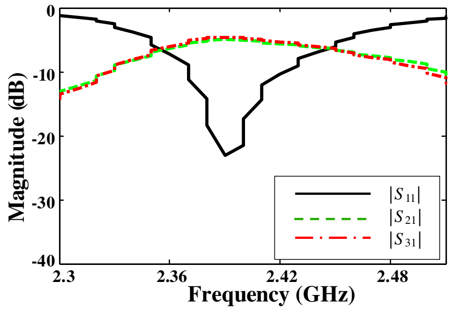

Figure 4. Measured narrow band frequency responses.

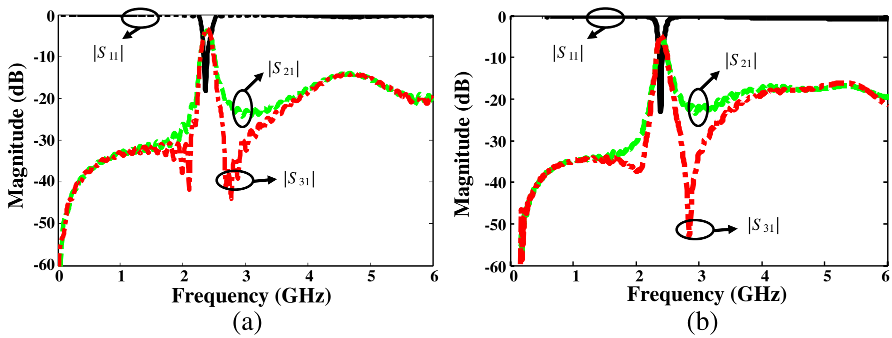

Figure 5. (a) Simulated wide frequency responses of the balun-BPF. (b) Measured wide frequency responses of the balun-BPF.

only for measurement convenience since the distance between ports 2 and 3 is too small to solder SMA connectors.

Simulated and measured results: For demonstration, the simple balun-BPF centered at 2.4 GHz is implemented on the substrate Rogers 4003 with dielectric constant of 3.38, loss tangent of 0.0027, and a thickness of 0.508 mm. The circuitry size of the balun-BPF is $13.75 \times 26\,\mathrm{mm}^2$, which is $0.18\lambda g \times 0.34\lambda g$. Simulations were performed using the circuit simulator CST Microwave Studio. The measurement was carried out on a test bench based on 8722ES vector network analyzer.

Figure 4 shows the measured narrow band frequency responses of the proposed balun-BPF in Fig. 3. The measured center frequency is 2.4 GHz, the measured 3-dB fractional bandwidth (FBW) is 5.8%, and the minimum insertion loss is 4.6 dB in each patch while the return loss is better than 20 dB.

The simulated and measured wide frequency responses are shown

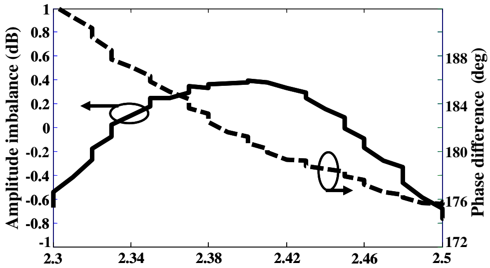

Figure 6. Amplitude imbalance and phase difference of the balun-BPF.

Table 1. Comparison of various balun-BPFS.

Refers	Insertion loss (dB)	Return loss (dB)	Size(λ_g*λ_g)	Phase imbalance (^{o})	imbalance(dB)
[1]	3+4.5	30	0.211*0.211	175–185	1.1
[2]	3+2.5	20	0.2875*0.3195	175–185	0.5
[3]	3+1.54	15	0.44*0.44	172–182	0.46
[5]	3+2.28	12	0.291*0.25	179–181	0.003
[6]	3+1.9	20	0.23*0.23	175–185	0.5
[7]	3+1.55	18	LTCC	177.7–182.3	0.26
[8]	3+1.43	20	0.213*0.203	179–181	0.2
This work	3+1.6	20	0.18*0.34	175–185	0.37

in Figs. 5 and 6 depicts the measured results of amplitude imbalance and phase difference. The amplitude imbalance is less than 0.39 dB from 2.34 GHz to 2.48 GHz, with the phase difference maintained within $180° \pm 5°$. At f_0, the amplitude imbalanced and phase difference are within 0.37 dB and 179.2°, respectively.

4. CONCLUSION

The proposed balun-BPF operated at 2.4 GHz has been experimentally verified in this paper. Compared with the existing balun-filters, the proposed balun-BPF has shown simpler construction, better size reduction and easier fabrication. At the same time, it also provides good balanced outputs in phase and magnitude. The differences between the two outputs are $180° \pm 5°$ in phase and within 0.39 dB in magnitude. At f_0, the amplitude imbalanced and phase difference are within 0.37 dB and 179.2°, respectively. The theoretical design, simulation, and experimental results are given and discussed, which show good agreement with each other. Thus, this compact balun-BPF can be employed in some RF systems which need either filter characteristic and balanced outputs, such as high frequency signal processing.

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