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RESEARCH ARTICLE

Design of a new balun bandpass filter with single-band balance and dual-band filtering characteristics

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Abstract

In this article, a new type of balun bandpass filter with single-band balance and dual-band filtering function is presented. For this purpose, a novel compact dual-mode open loop resonator with short-circuited stubs and interdigital capacitors is proposed. Two identical resonators are coupled to two output ports in order to obtain 180° phase difference between the output ports. By means of the changes in the short-circuited stubs and interdigital capacitors, control of the passbands at two output ports can be achieved. In addition, as the short-circuited stubs are located at the same wave traveling paths, phase difference cannot be obtained in the first passband and only the second passband has balun function. The designed balun bandpass filter was fabricated and tested for the experimental verifications. Phase difference and magnitude imbalance have been measured within 180° ± 2° and 0.5 dB, respectively. The measured results exhibit a very good agreement with the predicted results.

KEYWORDS

balun bandpass filter, interdigital capacitor, open loop resonator, short-circuited stub

1 | INTRODUCTION

In many microwave communication systems, there is an important demand of balun bandpass filters as they can transform an unbalanced input to balanced output ports. This can be achieved by obtaining 180° phase difference and same amplitude between the output ports. Therefore, balun bandpass filters eliminate the separate requirement of balun circuits and bandpass filter circuits, because they can combine both circuit features into only one system component. Three port balun circuits, that are the simplest design approaches, have a great attraction in recent years. Microstrip structures are often used in balun bandpass filter designs because of their advantages in terms of design flexibility, simple phase difference satisfaction, low insertion loss, and so on.

In recent years, studies on balun bandpass filter designs have been increased and many kind of balun bandpass filters have begun to appear. Among these, dual-band baluns,[1-4] highly selective baluns,[5,6] and wideband baluns[7,8] are the types that come to the forefront. In dual-band balun designs, using dual-mode resonators is the main design approach.[1-3] In the literature, some balun bandpass filters have only one transmission pole inside the passband,[3,4] so selectivity of the passbands cannot be obtained good enough. Balun design methodologies including standing wave pattern-based approaches,[2] conventional Marchand types,[3] coupled three microstrip lines,[9] and multilayer structures[10] have being especially considered by researchers.

In this article, a new compact dual-mode loop resonator designed by loading interdigital capacitors and short-circuited stubs is proposed. The interdigital capacitors and short-circuited stubs are used not only for obtaining dual resonance behavior, but also for miniaturization. They can also have influence on the resonance frequencies. The proposed resonators are utilized to design a balun bandpass filter. For this purpose, coupled three microstrip lines including one feeding line and two resonators are employed at the unbalanced port. Two identical resonators are used in the wave pattern of both balanced outputs. The designed circuit has two passbands at both outputs. However, only the second passband has balun function with 180° phase difference, whereas there is no phase difference in the first passband. The designed structure has been fabricated and measured in a good agreement with the predicted results. Magnitude and phase imbalances have been measured within 0.5 dB and 180° ± 2°.

2 | PROPOSED DUAL-MODE RESONATOR

Proposed dual-mode resonator is depicted in Figure 1A. As shown, the proposed resonator has two short-circuited stubs located at the bottom of an open loop resonator (OLR) and an interdigital capacitor between the open ends. An RT/duroid (Rogers Corporation, Chandler, AZ) substrate with a dielectric constant of 6.15 and a thickness of 1.27 mm is used. Dimensions of the proposed resonator are given in Table 1. All simulations are realized by full-wave electromagnetic simulator.[11] Effects of the presence of short-circuited stubs and interdigital capacitor on the frequency responses are illustrated in Figure 1B. It is clear that those components increase the electrical length of the resonator, so resonance frequency of the resonator can be decreased. In other words, the resonance frequency can be dropped from 2.15 to 1.73 GHz. Hence, a miniaturization of about 20% can be achieved. It should also be noted that only one resonance frequency occurs without grounding the high impedance stubs. After grounding, the resonance frequency split into two resonance frequencies at the lower and higher sides of its. In this case, the first resonance frequency occurs at about 1.34 GHz. Hence the miniaturization level can be enhanced to about 42%. Both of the resonance frequencies can be controlled due to the changes in the stub lengths and interdigital capacitor as in Figure 2. Figure 2A represents the effects of the short-circuited stub length, *s*, on the frequency response. As can be seen, both of the resonance frequencies can be simultaneously controlled. Effects of the interdigital capacitor on the frequency response are depicted in Figure 2B. As is well known, capacitance of an interdigital capacitor can be calculated with respect to the finger numbers and lengths.[12] In this work, capacitance change is investigated according to the change in the finger number, *n*. It is clear that the second resonance frequency can be independently controlled by means of the interdigital capacitor. It can be said that the proposed resonator allows controlling both resonance frequencies independently. Besides, it has a compact circuit size, which may be considered as an important milestone for the utilization in balun bandpass filter designs as reported in this paper.

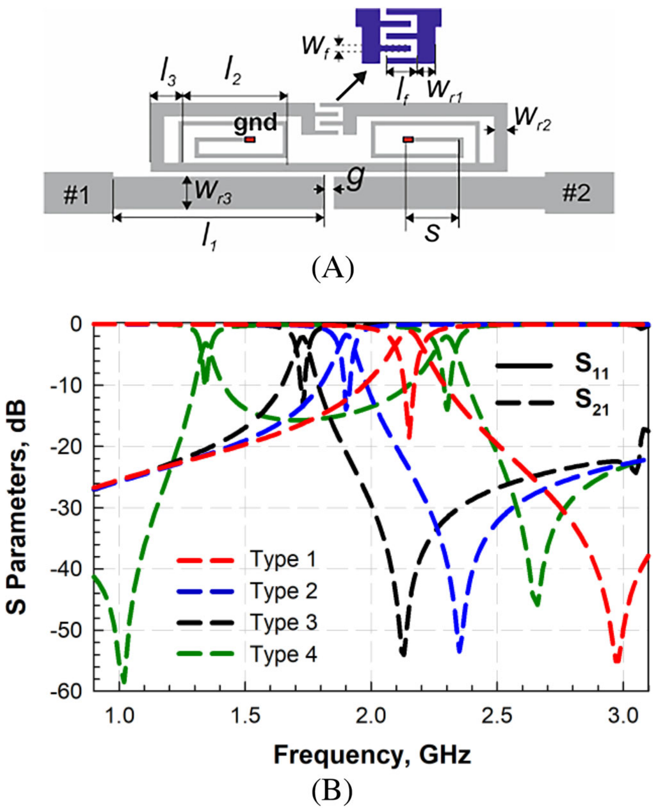


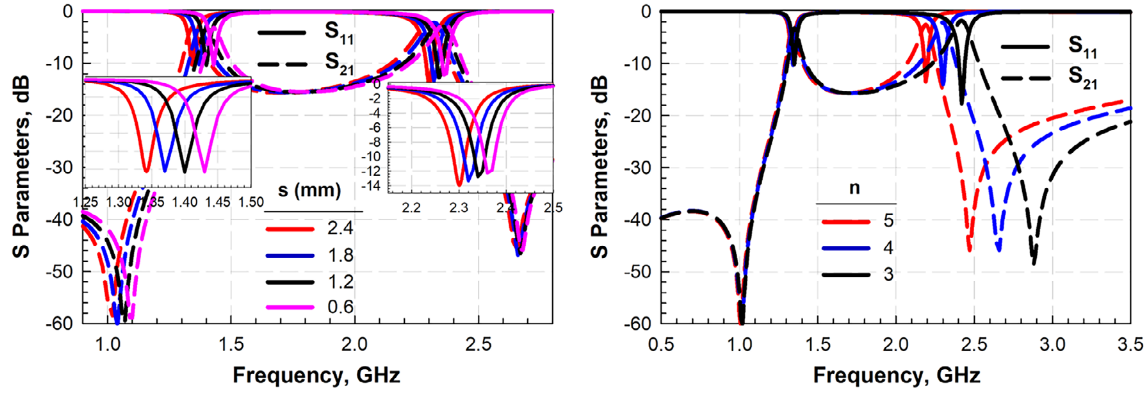
FIGURE 1 A, Configuration of the proposed resonator under weak coupling; B, Effects of the presence of short-circuited stubs and interdigital capacitor (type 1: only an OLR, type 2: an OLR with interdigital capacitor, type 3: an OLR with interdigital capacitor and open-circuited stubs, type 4: an OLR with interdigital capacitor and short-circuited stubs). OLR, open loop resonator [Color figure can be viewed at wileyonlinelibrary.com]

3 | BALUN BANDPASS FILTER DESIGN

By using the proposed dual-mode resonator, a novel balun bandpass filter is designed as shown in Figure 3. As can be seen from the figure, two signal paths between the unbalanced input and balanced outputs are constructed. Thus, 180° phase difference can be obtained between the balanced outputs. It should also be noted that the proposed resonators are coupled to the unbalanced input port by means of coupled three microstrip lines. It is clear that the bottom edges of the resonators are coupled to the open-circuited transmission line that comes from the input port. As the proposed resonator has two resonance frequencies, dual passbands can be obtained. Therefore, it is expected to obtain dual-band balun bandpass filter response. However, short-circuited stubs are located at the similar wave traveling paths, so the first passband does not exhibit balun property because of same phases in the balanced outputs. Hence, the designed structure may be categorized as a balun bandpass filter with single-band balun and dual-band filtering function. On the other hand, two identical resonators are coupled to each other in order to obtain two transmission poles inside

TABLE 1 Dimensions of the proposed resonator (mm)

l_1	l_2	l_3	l_f	l_{feed1}	l_{feed2}	w_{r1}	w_{r2}	w_{r3}	w_f
9.1	4.5	1.4	1.0	18.0	15.4	0.6	0.6	1.4	0.2



(A) (B)

FIGURE 2 Center frequency control due to the change in A, lengths of the short-circuited stubs; and B, capacitance of the interdigital capacitor [Color figure can be viewed at wileyonlinelibrary.com]

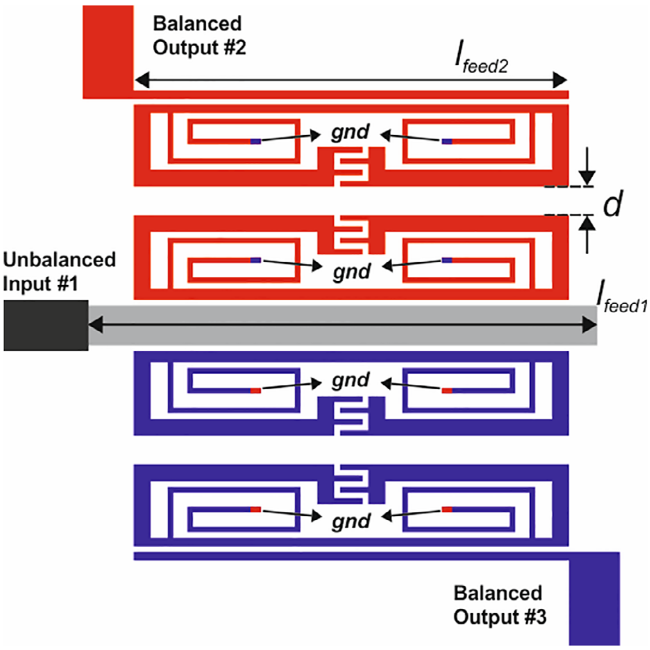


FIGURE 3 Layout of the proposed microstrip balun bandpass filter [Color figure can be viewed at wileyonlinelibrary.com]

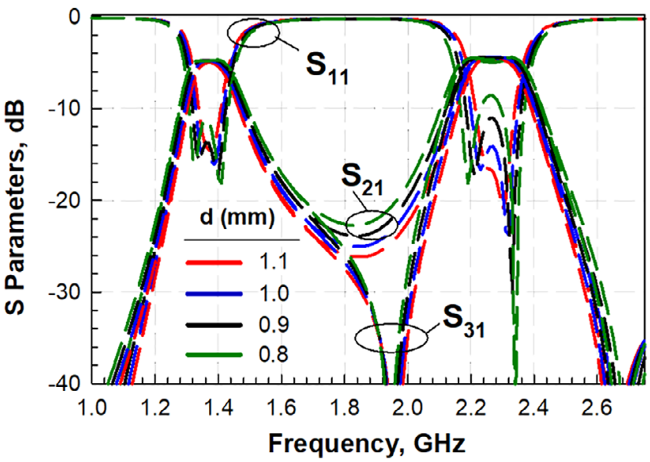


FIGURE 4 Bandwidth controls of the passbands with respect to the change in *d* [Color figure can be viewed at wileyonlinelibrary.com]

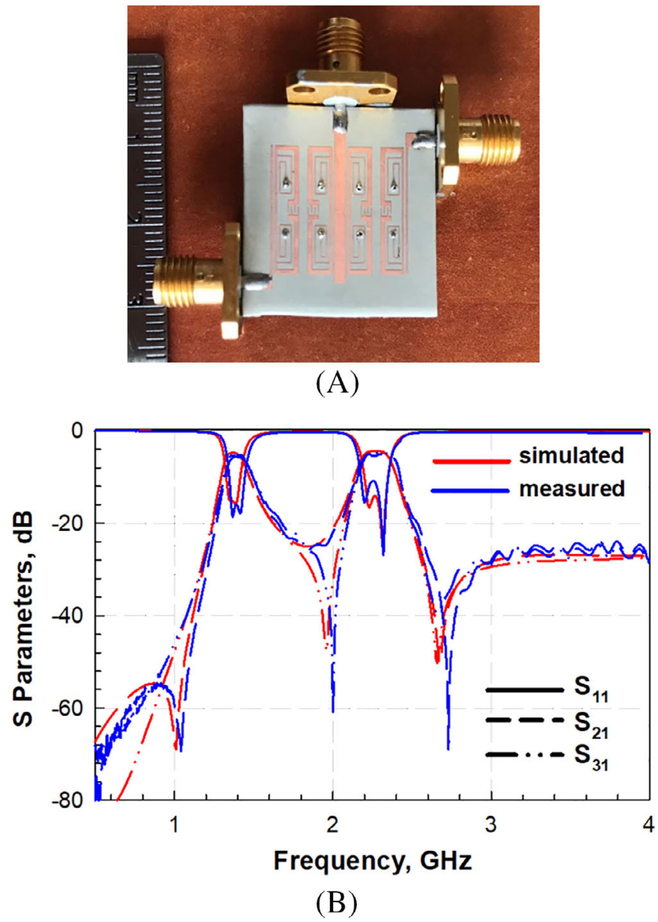


FIGURE 5 A, Photograph of the fabricated circuit; B, Comparison of the measured and simulated results for *S* parameters [Color figure can be viewed at wileyonlinelibrary.com]

the passbands. They can occur more transmission zeros and also improve the selectivity of the passbands.

Bandwidth of the designed balun bandpass filter can be controlled with respect to the change in the distance between the identical resonators, *d*. Bandwidths of the both passbands can be simultaneously controlled as shown in Figure 4. While the Fractional Bandwidth (FBW) of the first passband

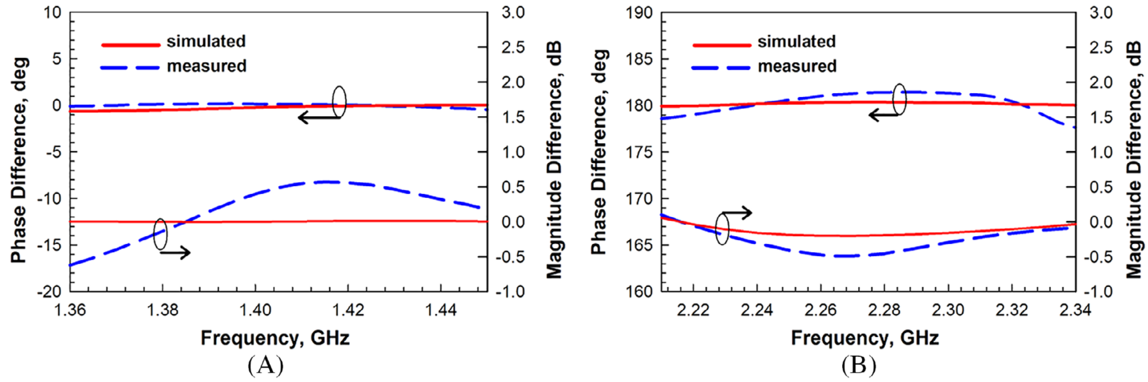


FIGURE 6 Comparison of the measured and simulated results of phase difference and magnitude imbalance for A, first passband; B, second passband [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Comparisons with the reported works

	Number of filter/balun bands	*f1/f2* (GHz)	PI (deg)	MI (dB)	IL (dB)	Circuit size ($\lambda_g \times \lambda_g$)
[2]	2/2	2.28/2.72	<4.4	<0.34	0.9/1.0	0.63 × 0.46
[3]	2/2	2.4/5.2	<2	<0.3, <0.34	1.32/1.26	0.2 × 0.2
[5]	1/1	2.78/-	<5	<0.5	1.2	NA
[10]	2/2	1.55/2.35	<4.5	<0.3	1.45/1.45	0.219 × 0.219
This work	2/1	1.39/2.29	<2 (at second passband)	<0.5	2.15/1.7	0.182 × 0.159

is controlled between 7% and 11%, FBW of the second passband can be controlled between 6.5% and 10.6%. It should also be noted that the control range is limited to obtain suitable return loss levels inside the passbands. The reason of narrow bandwidth control range is resulted from the nature of the designed circuit topology, as the passbands are created from the separate resonance frequencies.

4 | EXPERIMENTAL RESULTS

The designed balun bandpass filter was fabricated for the experimental confirmation of the proposed approach. Photograph of the fabricated balun is illustrated in Figure 5A. In the fabricated circuit, *d*, *s*, and *n* are chosen as 1.0 mm, 2.4 mm and 4, respectively. All gaps between the resonators and coupled lines are 0.2 mm. Total circuit size of the designed circuit excluding input and output ports is 19.0 × 16.6 mm^2. That corresponds to 0.182 $\lambda_g \times 0.159\ \lambda_g$, where λ_g is the guided wavelength at the lowest resonant frequency. The fabricated balun bandpass filter has also been measured with a Vector Network Analyzer of Agilent E5071C (Keysight Technologies, CA). Comparisons of the measured and simulated results for *S* parameters are shown in Figure 5B in a good agreement. The passbands have been measured at 1.39 and 2.29 GHz with the FBWs of about 8.70% and 8.73%, respectively. The measured insertion losses are smaller than 2.15 and 1.7 dB for the first and second passbands, respectively. Return losses have been measured as better than 12 dB. Figure 6A,B represents the magnitude imbalance and phase difference. According to Figure 6A, there is no balancing operation in the first passband. From Figure 6B, it is clear that the magnitude imbalance between the balanced outputs has been measured within 0.5 dB. Also, phase difference has been obtained as better than 180° ± 2°.

The proposed circuit exhibits dual-band filtering characteristics at both output ports. While one of the balanced output ports has a transmission zero near the first passband, the other one has not. In addition, the second passband exhibits balun bandpass filter characteristics, where the first passband is employed as the power divider. Therefore, the designed circuit has a significant novelty depending on its new approach. The designed structure has also acceptable compactness as compared to the reported balun bandpass filters given in Table 2.

5 | CONCLUSION

A new type of balun bandpass filter with single-band balance and dual-band filter characteristics has been designed, fabricated, and tested. The proposed balun bandpass filter has been formed by coupling a new dual-mode resonator to unbalanced input and balanced output ports. The proposed resonator has been constructed by loading short-circuited stubs and interdigital capacitors to an OLR. As the short-circuited stubs have been located at the similar wave traveling path, phase difference of 180° has not been obtained between the balanced output ports in the first passband. Therefore, the first passband can be employed as a power divider. In order to use the designed structure as a dual-band balun bandpass filter, an extra balun structure is needed. By this way, the designed circuit may be considered for the utilization in multifunction communication systems. The designed circuit has significant advantages in terms of compact circuit size, low phase, and magnitude imbalances.

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