Dual-wideband band pass filter using folded cross-stub stepped impedance resonator

by Teguh Firmansyah

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Dual-wideband band pass filter using folded cross-stub stepped impedance resonator

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Abstract

In this letter, a dual-wideband band pass filter (DW-BPF) using cross-stub stepped impedance resonator (CS-SIR) was simulated, fabricated, and measured accordingly. The CS-SIR was used to replace the conventional half-wavelength open stub resonators. Compare to the conventional resonator, the CS-SIR resonator has a wider fractional bandwidth and ease of fabrication. Furthermore, the DB-BPF was fabricated on microstrip with $\varepsilon_r = 4.4$, $h = 0.8$ mm, and tan $\delta = 0.0265$. The DW-BPF with CS-SIR achieves transmission-coefficients/fractional-bandwidth of 0.22 dB/94.19% and 1.87 dB/33.52% at 1.14 GHz and 2.31 GHz, respectively. In order to reduce the filter size, a folded CS-SIR (FCS-SIR) was also proposed. As a result, this BPF size was reduced to 53%, with the BPF size of 0.30 λ_G^2 and 0.14 λ_G^2 for DW-BPF with CS-SIR and DW-BPF with folded CS-SIR, respectively. The λ_G is the wavelength at the first frequency. Further, the DW-BPF with FCS-SIR achieves transmission coefficients/fractional bandwidth of 0.19 dB/89.08% and 1.29 dB/31.90% at 1.21 GHz and 2.41 GHz, respectively. Measured results are in a very good agreement with the simulated results.

KEYWORDS

dual-wideband band pass filter, stepped impedance resonator, transmission zero

1 | INTRODUCTION

A dual-band band pass filter (DB-BPF) is an important component of a radio transceiver for reducing interference and noise at two frequency bands simultaneously.[1] Therefore, the pursuit of a DB-BPF with good-performances has become a key trend in the field of research. A variety of design

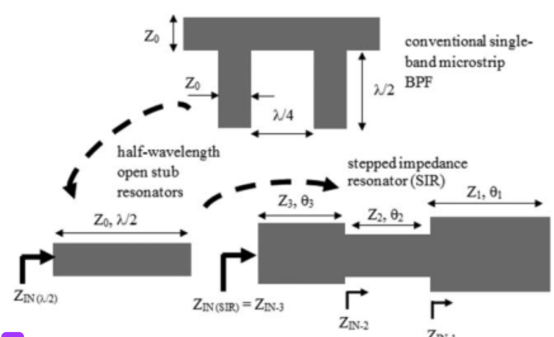

FIGURE 1 The conventional half-wavelength open stub resonator replaced by stub-stepped impedance resonator

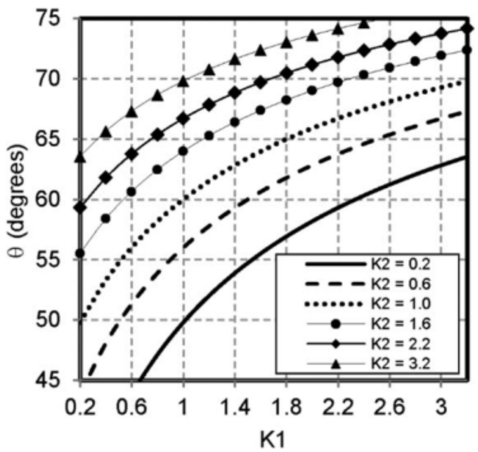

FIGURE 2 The relationship between impedance ratio (K_1, K_2) and electrical length (θ)

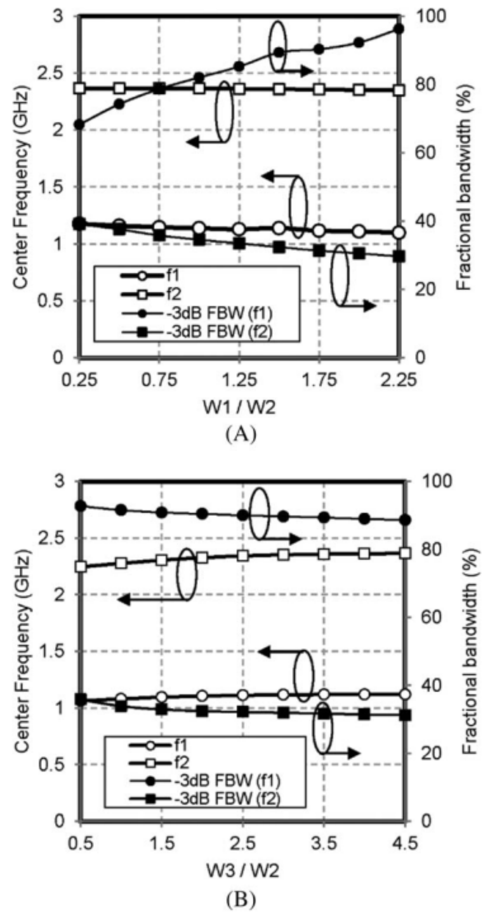

FIGURE 4 (A) The dependency of the center frequency and fractional bandwidth on the impedance ratio (W_1/W_2). (b) The stability of the center frequency and fractional bandwidth on the impedance ratio (W_3/W_2)

techniques is frequently used for DB-BPF design such as square loop dual mode resonator,[2] defected ground structure (DGS),[3,4] spiral resonators,[5] defected stepped impedance resonator (Defected-SIR),[6,7] slotted stepped impedance resonator (Slotted-SIR),[8] multilayer stepped impedance resonator (Multilayer-SIR),[9,10] meandering stepped impedance resonators (Meandering-SIR),[11] stub-loaded stepped impedance resonator (Stub-loaded SIR),[12] and coupled stepped impedance resonator (Coupled-SIR).[13] However, the DB-BPFs proposed by[1–13] still possess a complex geometry and achieve a narrow bandwidth.

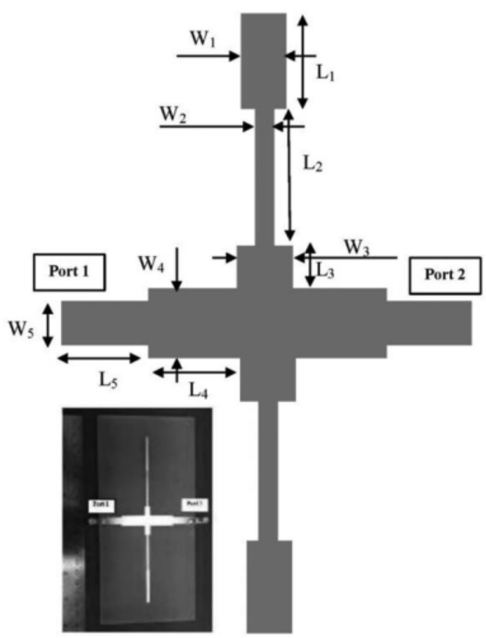

FIGURE 3 The layout and photograph of the design DW-BPF using CS-SIR

As a novelty in this letter, we propose a dual-wideband band pass filter (DW-BPF) using cross-stub stepped impedance resonator (CS-SIR). Figure 1 shows a CS-SIR which was used to replace the conventional half-wavelength open stub resonators. A folded CS-SIR (FCS-SIR) was also proposed to reduce the filter size. Thus, the BPF size is reduced to 53%. The proposed design could be validated by simulations and measurements. This letter is organized as follows: Section 2 briefly describes the design of the proposed DW-BPF using CS-SIR, Section 3 presents the simulated and experimental results, and finally, Section 4 concludes this research.

2 | PROPOSED DUAL-WIDEBAND BAND PASS FILTER

A half-wavelength open stub resonator structure was commonly used to design the conventional single-band

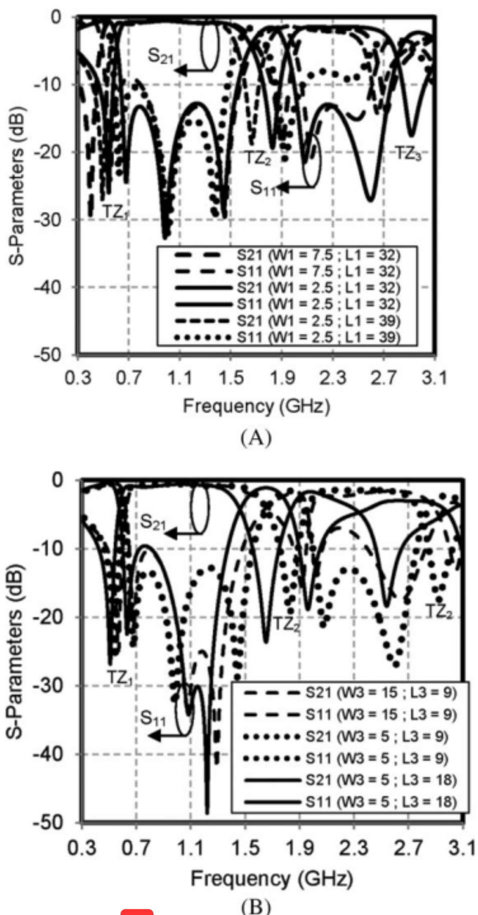

FIGURE 5 (A) Transmission coefficients (S_{21}) and reflection coefficients (S_{11}) response with varied W_1 and L_1. (B) Transmission coefficients (S_{21}) and reflection coefficients (S_{11}) response with varied W_3 and L_3

microstrip BPF.[1] In this letter, the half-wavelength open stub resonator is converted to the stub stepped impedance resonator as shown in Figure 1. The CS-SIR structure consists of three transmission lines having different characteristic impedances Z_N ($N = 1,2,3$) with corresponding electrical lengths θ_N ($N = 1,2,3$), respectively. Analyzing the input impedance $Z_{IN(SIR)}$ of the stepped impedance resonator section, the following equations can be derived:

$$Z_{IN(1)} = -jZ_1 \cot\theta_1 \tag{1}$$

$$Z_{IN(2)} = Z_2 \frac{Z_{IN(1)} + jZ_2 \tan\theta_2}{Z_2 + jZ_{IN(1)} \tan\theta_2} \tag{2}$$

$$Z_{IN(SIR)} = Z_{IN(3)} = Z_3 \frac{Z_{IN(2)} + jZ_3 \tan\theta_3}{Z_3 + jZ_{IN(2)} \tan\theta_3} \tag{3}$$

Equation (3) can also be expressed as:

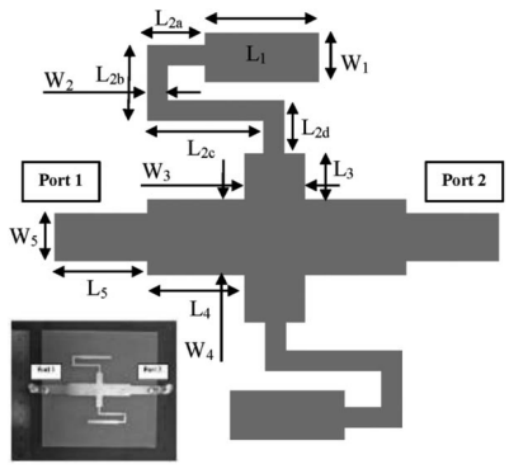

FIGURE 6 The layout and photograph of the design DW-BPF using folded CS-SIR (FCS-SIR)

$$Z_{IN(SIR)} = Z_1 \frac{Z_2(-jZ_3 \cot\theta_3 + jZ_2 \tan\theta_2) + jZ_1 \tan\theta_1 (Z_2 + Z_3 \cot\theta_3 \tan\theta_2)}{Z_1 Z_2 + Z_1 Z_3 \cot\theta_3 \tan\theta_2 + Z_2 Z_3 \cot\theta_3 \tan\theta_1 - Z_2{}^2 \tan\theta_2 \tan\theta_1} \tag{4}$$

The resonant frequencies can be extracted from admittance condition $Y_{IN(SIR)} = 0$ or impedance condition $Z_{IN(SIR)} = \infty$.[1] This can be obtained when:

$$Z_2{}^2 \tan\theta_3 \tan\theta_1 \tan\theta_2 - Z_1 Z_2 \tan\theta_3 - Z_1 Z_3 \tan\theta_2 - Z_2 Z_3 \tan\theta_1 = 0 \tag{5}$$

with the Z_N ($N = 1,2,3$) and θ_N ($N = 1,2,3$) stand for the characteristic impedance and electrical length, respectively. For the same electrical length $\theta_1 = \theta_2 = \theta_3 = \theta$, the resonance condition can also be shortened as follows:

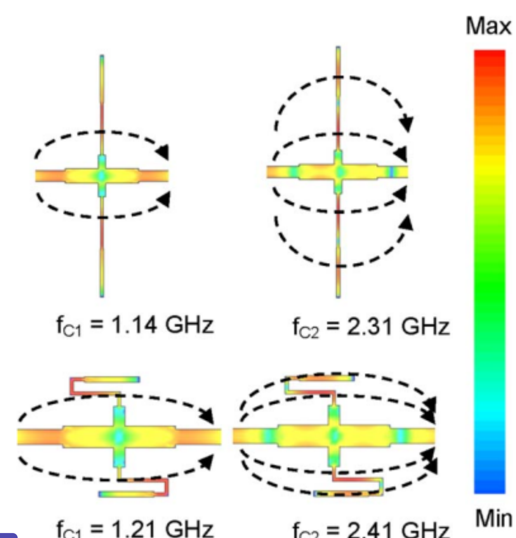

FIGURE 7 The surface current of the DW-BPF with CS-SIR and FCS-SIR. [Color figure can be viewed at wileyonlinelibrary.com]

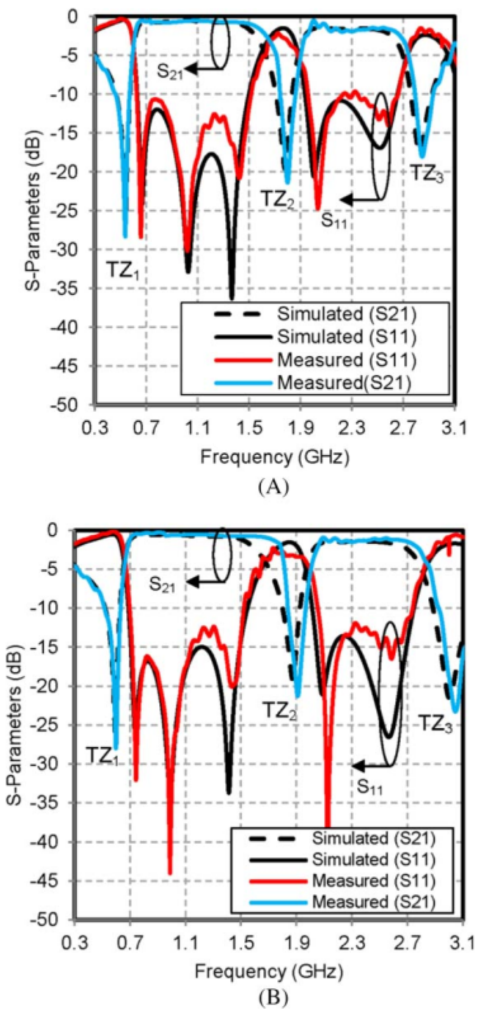

FIGURE 8 (A) Comparison between simulated and measured results of DW-BPF using CS-SIR. (B) Comparison between simulated and measured results of DW-BPF using FCS-SIR. [Color figure can be viewed at wileyonlinelibrary.com]

$$\tan^3\theta - K_1\tan\theta - K_1K_2\tan\theta - K_2\tan\theta = 0 \tag{6}$$

which can also be expressed as:

$$\tan\theta\ \left(\tan\theta + \sqrt{K_1+K_1K_2+K_1}\right)\left(\tan\theta\ - \sqrt{K_1+K_1K_2+K_1}\right) = 0 \tag{7}$$

where the impedance ratio K_N (1,2) is defined by:

$$K_1 = \frac{Z_1}{Z_2},\ \text{and} \tag{8}$$

$$K_2 = \frac{Z_3}{Z_2} \tag{9}$$

respectively. Equation (4) shows that the resonator provides two resonating frequencies. Therefore, the resonator serves as a dual mode resonator to produce two resonant frequencies. The relationship of K_1, K_2, and θ is shown in Figure 2.

3 | RESULTS AND DISCUSSION

Figure 3 shows the schematic of the design DW-BPF using CS-SIR. The DW-BPF was fabricated on microstrip with $\varepsilon_r = 4.4$, $h = 0.8$ mm, and tan $\delta = 0.0265$. The DW-BPF consists of input/output port (*I*/*O*) line and two stub-SIR placed in a crossed manner. The DW-BPF was simulated using advanced design system (ADS) software, whereby an RS-ZVA vector network analyzer (VNA) was used to test the fabricated prototype of DW-BPF. The dimensions are given as follows (all in millimeters): $L_1 = 32$, $L_2 = 35$,

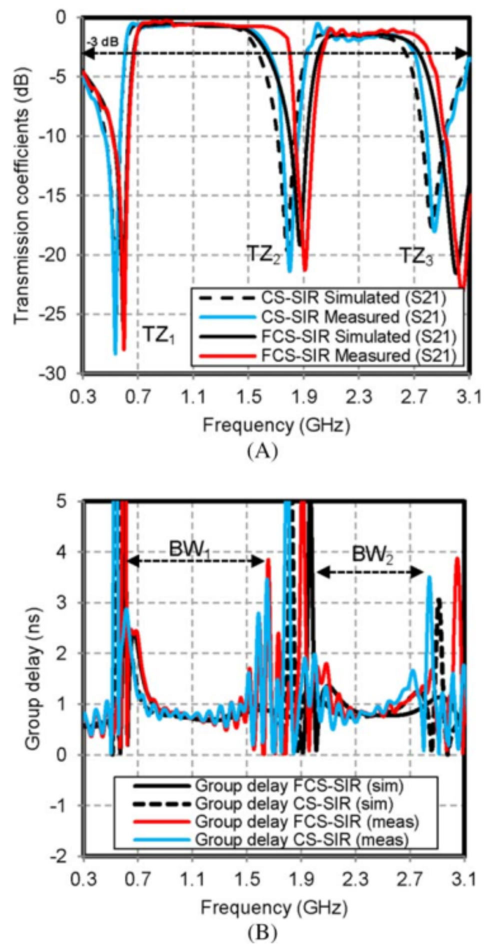

FIGURE 9 (A) Comparison of transmission coefficients (S_{21}) between DW-BPF using CS-SIR and DW-BPF using FCS-SIR. (B) Comparison of group delays (GDs). [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Summary of the proposed dual-wideband BPF comparison

Ref.	Method	Center frequency (GHz)	Transmission coefficients (dB)	–3 dB FBW (%)
[2]	Square loop dual mode resonator	3.45/6.65	0.70/1.20	14.49/8.27
[3]	Defected ground structure (DGS)	4.60/7.30	0.34/0.35	3.87/2.12
[4]	Defected ground spiral resonator	1.87/2.43	2.00/2.00	4.50/3.30
[5]	Four spiral resonators	1.80/2.40	1.6/2.5	5.60/3.00
[6]	Defected stepped impedance resonator (Defected-SIR)	2.35/3.15	0.50/1.5	3.90/2.80
[7]	Defected stepped impedance resonator (Defected-SIR)	1.85/2.35	0.50/1.00	5.50/4.50
[8]	Slotted stepped impedance resonator (Slotted-SIR)	2.40/3.50	1.80/2.9	4.10/1.40
[9]	Multilayer stepped impedance resonator (Multilayer-SIR)	2.45/5.80	1.35/0.98	3.06/2.16
[10]	Multilayer stepped impedance resonator (Multilayer-SIR)	2.40/5.20	1.20/1.50	5.40/7.30
[11]	Meandering stepped impedance resonators (Meandering-SIR)	2.40/5.25	0.72/2.10	8.33/3.85
[12]	Stub-loaded stepped impedance resonator (Stub-loaded SIR)	2.40/5.20	1.20/2.00	8.00/5.00
[13]	Coupled stepped impedance resonator (Coupled-SIR)	2.4/3.8	0.50/1.00	8.33/5.26
This Work	Cross-stub stepped impedance resonator (CS-SIR)	1.14/2.31	0.22/1.87	94.19/33.52
	Folded cross-stub stepped impedance resonator (FCS-SIR)	1.21/2.41	0.19/1.29	89.08/31.90

$L_3 = 9.0$, $L_4 = 23$, $L_5 = 21$, $W_1 = 2.5$, $W_2 = 1.5$, $W_3 = 5.0$, $W_4 = 10$, and $W_5 = 7.0$.

The dependency of the center frequency and fractional bandwidth on the impedance ratio (W_1/W_2) is given in Figure 4A. The figure shows that by increasing the impedance ratio (W_1/W_2), the center frequencies will be stable. However, increasing impedance ratio (W_1/W_2) would raise the fractional bandwidth. Figure 4B also shows the stability of the center frequency and fractional bandwidth on the variance of impedance ratio (W_3/W_2). The chart shows that both center frequency and fractional bandwidth were not changed significantly. Figure 5A and B shows transmission coefficients (S_{21}) and reflection coefficients (S_{11}) in response to varied W_1, W_3, L_1, and L_3.

In order to reduce the filter size, a folded CS-SIR (FCS-SIR) was proposed as shown in Figure 6. The dimensions are given as follows (all in millimeters): $L_1 = 32$, $L_{2a} = 5$, $L_{2b} = 5$, $L_{2c} = 20$, $L_d = 5$, $L_3 = 9.0$, $L_4 = 23$, $L_5 = 21$, $W_1 = 2.5$, $W_{2a} = W_{2b} = W_{2c} = W_{2d} = 1.5$, $W_3 = 5.0$, $W_4 = 10$, and $W_5 = 7.0$. As a result, this BPF size was reduced to 53%. Furthermore, both DW-BPF using CS-SIR and folded CS-SIR (FCS-SIR) were accomplished with two pass bands. Figure 7 shows the surface current at filter with CS-SIR and FCS-SIR. It shows that the first center frequency will obtain maximum value of surface current at transmission line 2 (W_2, L_2) and the second center frequency will obtain maximum value of surface current at transmission line 1 (W_1, L_1) and transmission line 3 (W_3, L_3).

Figure 8A shows a comparison between simulated and measured of DW-BPF using CS-SIR. A DW-BPF with CS-SIR achieves transmission-coefficients/fractional-bandwidth of 0.22 dB/94.19% and 1.87 dB/33.52% at 1.14 GHz and 2.31 GHz, respectively. The transmission zeros (TZ) of this filter are −28.29 dB, −21.36 dB, and −18.02 at 0.53 GHz, 1.79 GHz, and 2.86 GHz, respectively. Furthermore, Figure 8B shows a comparison between simulated and measured of

DW-BPF using FCS-SIR. A DW-BPF with FCS-SIR achieves transmission coefficients/fractional bandwidth of 0.19 dB/89.08% and 1.29 dB/31.90% at 1.21 GHz and 2.41 GHz, respectively. The transmission zeros (TZ) of this filter are −27.94 dB, −21.25 dB, and −23.25 at 0.59 GHz, 1.90 GHz, and 3.04 GHz, respectively. Figure 9A shows a comparison of transmission coefficients (S_{21}) between DW-BPF using CS-SIR and DW-BPF using FCS-SIR. The measured group delays (GDs) of all pass bands below 5 ns are also depicted in Figure 9B. Table 1 summarizes the comparison of the proposed dual band BPF. Finally, the measured results are in a very good agreement with the simulated results.

4 | CONCLUSION

This letter proposes a dual-wideband band pass filter (DW-BPF) using cross-stub stepped impedance resonator (CS-SIR). The CS-SIR was used to replace the conventional half-wavelength open stub resonators. In order to reduce the filter size, a folded CS-SIR (FCS-SIR) also was proposed. As a result, this BPF size is reduced to 53%. Measured results are in a very good agreement with the simulated results. In comparison with the previous works, both of BPF using CS-SIR and BPF using FCS-SIR could produce wider bandwidth, good transmission coefficients, and ease of fabrication.

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A new filter antenna using improved stepped impedance hairpin resonator

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Abstract

In this letter, a filter antenna based on novel wide stopband low-pass filter has been presented. The introduction

Dual-wideband band pass filter using folded cross-stub stepped impedance resonator

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