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

**Teguh Firmansyah**[1] | **Supriyanto Praptodinoyo**[1] | **Romi Wiryadinata**[1] | **Suhendar Suhendar**[1] | **Siswo Wardoyo**[1] | **Alimuddin Alimuddin**[1] | **Cindy Chairunissa**[2] | **Mudrik Alaydrus**[3] | **Gunawan Wibisono**[4]

[1] Department of Electrical Engineering, University of Sultan Ageng Tirtayasa, Cilegon, Banten 42435, Indonesia

[2] School of Engineering, Electronics, University of Edinburgh, Edinburgh EH9 3JN, United Kingdom

[3] Department of Electrical Engineering, Universitas Mercu Buana, Meruya, Jakarta 11650, Indonesia

[4] Department of Electrical Engineering, Universitas Indonesia, Kampus Baru UI, Depok 16424, Indonesia

**Correspondence**
Teguh Firmansyah, Department of Electrical Engineering, University of Sultan Ageng Tirtayasa, Cilegon, Banten 42435, Indonesia.
Email: teguhfirmansyah@untirta.ac.id

**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 $\lambda_G^2$ and 0.14 $\lambda_G^2$ for DW-BPF with CS-SIR and DW-BPF with folded CS-SIR, respectively. The $\lambda_G$ 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

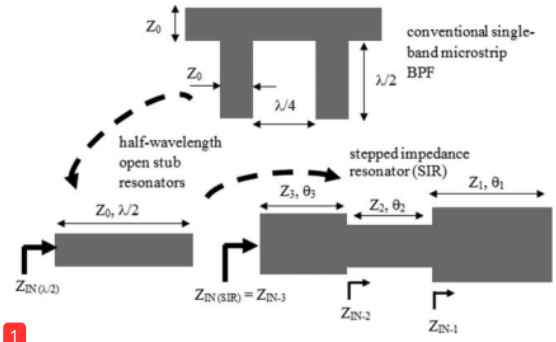



**FIGURE 1** The conventional half-wavelength open stub resonator replaced by stub-stepped impedance resonator

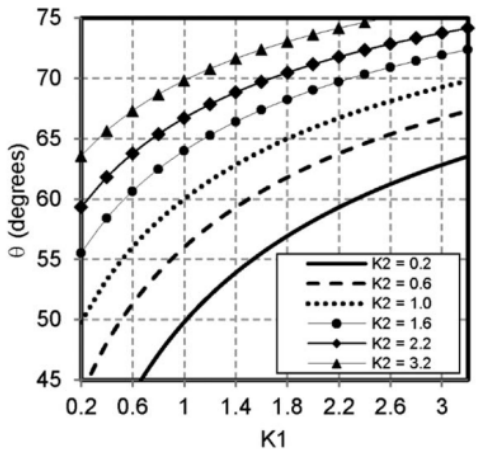



**FIGURE 2** The relationship between impedance ratio ($K_1$, $K_2$) and electrical length (θ)

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.

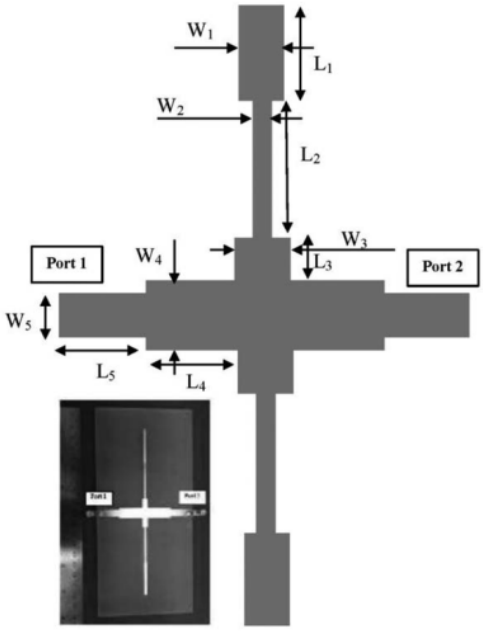
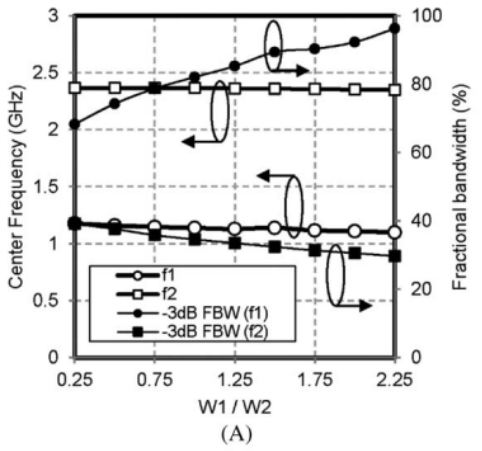



**FIGURE 3** The layout and photograph of the design DW-BPF using CS-SIR



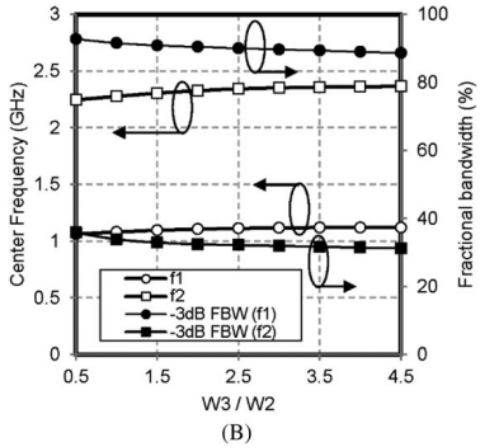
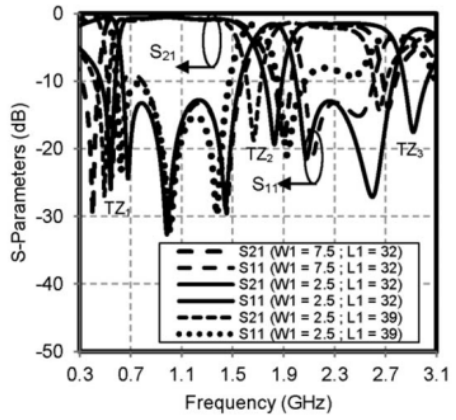




**FIGURE 4** (A) The dependency of the center frequency and fractional bandwidth on the impedance ratio ($W_1/W_2$). (b) The stability of the center frequency and fractional bandwidth on the impedance ratio ($W_3/W_2$)

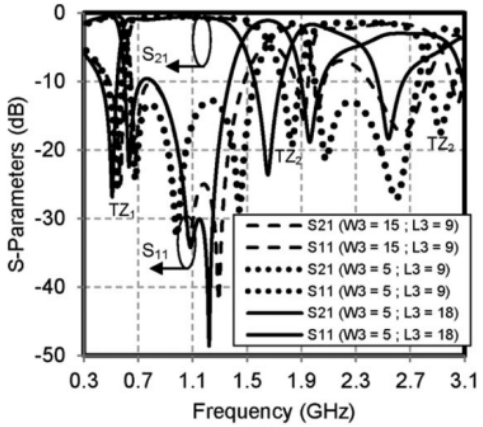
As a novelty in this letter, we propose a dual-wideband band pass filter (DW-BPF) using cross-stub stepped impedance resonator (CS-SIR). Figure 1 shows a CS-SIR which was used to replace the conventional half-wavelength open stub resonators. A folded CS-SIR (FCS-SIR) was also proposed to reduce the filter 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




(A)




(B)

**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 $\theta_N$ ($N$ = 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:

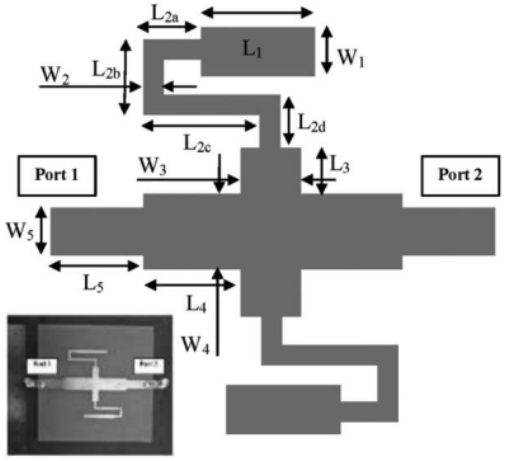



**FIGURE 6** The layout and photograph of the design DW-BPF using folded CS-SIR (FCS-SIR)

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

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 $\theta_N$ ($N$ = 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:

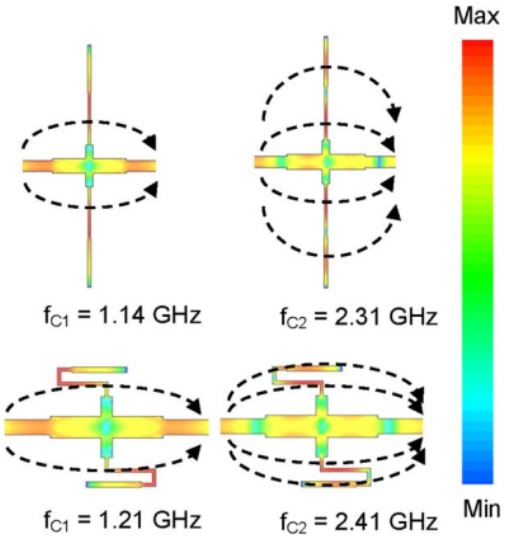



**FIGURE 7** The surface current of the DW-BPF with CS-SIR and FCS-SIR. [Color figure can be viewed at wileyonlinelibrary.com]

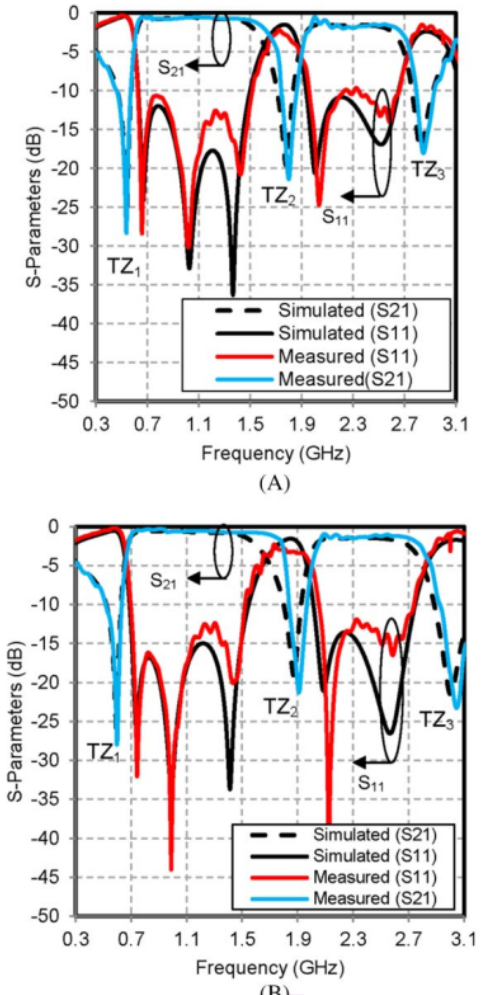



**FIGURE 8** (A) Comparison between simulated and measured results of DW-BPF using CS-SIR. (B) Comparison between simulated and measured results of DW-BPF using FCS-SIR. [Color figure can be viewed at wileyonlinelibrary.com]

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

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): $L_1 = 32$, $L_2 = 35$,

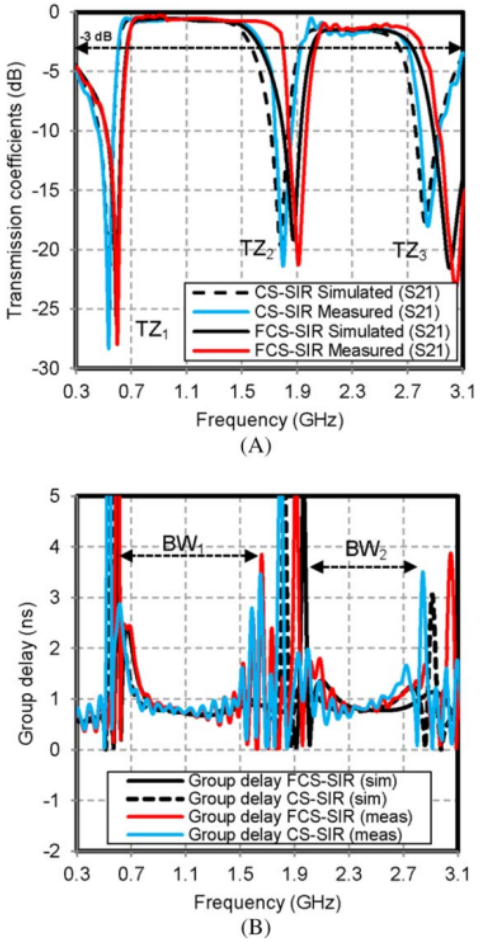



**FIGURE 9** (A) Comparison of transmission coefficients ($S_{21}$) between DW-BPF using CS-SIR and DW-BPF using FCS-SIR. (B) Comparison of group delays (GDs). [Color figure can be viewed at wileyonlinelibrary.com]

**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.

## ACKNOWLEDGMENTS

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# A new filter antenna using improved stepped impedance hairpin resonator

**Dan Feng | Huiqing Zhai | Lei Xi | Kedi Zhang | Dong Yang**

National Key Laboratory of Antennas and Microwave Technology, School of Electronic Engineering, Xidian University, Xi'an, Shaanxi 710071, China

**Correspondence**
Huiqing Zhai, National Key Laboratory of Antennas and Microwave Technology, School of Electronic Engineering, Xidian University, Xi'an, Shaanxi 710071, China.
Email: hqzhai@mail.xidian.edu.cn

**Abstract**

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

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