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Wide Stopband Microstrip Triplexer Using Common Crossed Resonator and Uniform Impedance Resonator

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Abstract—A novel microstrip triplexer with a common crossed resonator and some uniform impedance resonators (UIR) is proposed in this paper. The crossed resonator is theoretically analyzed and proved to be able to resonate at three different frequencies. By using the crossed resonator as the common resonator, a compact structure can be gained as no extra matching network is needed, and the number of the resonator can be reduced effectively. Moreover, a wide stopband is obtained by setting the crossed resonator and UIRs working at the same fundamental frequencies but different higher order resonant frequencies. To demonstrate the design procedure, a triplexer with a third order Chebyshev response in each channel is fabricated and measured. The measured result is in good agreement with the simulated one, showing an attenuation of 20 dB up to 8 times the first channel frequency.

1. INTRODUCTION

Multiplexers play an important role in modern communication system for signal separation or combination in both receivers and transmitters. A multiplexer usually consists of several bandpass filters and an impedance matching network. The filters are used for signal selecting and the matching network aims to realize the isolation between different channels. However, the limitation of space requires the size of the multiplexer small enough to be put into application when the size of the device comes to have a higher priority. Additionally, multiplexers with a wide stopband are essential for the design of transceivers.

Traditional triplexer design usually cannot skip the procedure of selecting a suitable matching network [1–3]. But the existence of matching network usually leads to a more complex design procedure and goes against the propose of miniaturization. Besidesit is difficult to find such a matching network that can work in a multiplexer. By using a multi-mode resonator as a common resonator shared by different channels, the matching network is not needed and the number of resonators can be reduced. Several works have been done on this issue [4–7]. But most of them were studying about diplexers and the work on triplexers is much less. Among various resonators, the most popular common resonator is SIR. In [4, 5], a SIR was used as a common resonator to form a diplexer. By properly design the length and the width of the SIR, it can resonate at two or more different frequencies. A triplexer using SIR as common resonator was presented in [6], but the wide band performance is not given. Moreover, a T-shaped resonator which can provide two extremely close resonance frequencies can also be used as a common resonator in a diplexer [7], but the stopband of the diplexer is not wide enough.

In [8], a novel cross-shaped resonator was presented and proved to be able to resonant at three controllable frequencies. Based on this work, a triplexer based on a common crossed resonator is designed and measured. The triplexer has a third order Chebyshev response in each channel. Compared to conventional ones, the proposed triplexer has a compact structure through involving common resonator

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and a wide stopband by irregularly distributing the higher order spurious frequencies of the resonators in a bandpass filter [9]. An experimental prototype is designed and measured and is predicted by the full-wave model.

2. CROSSED RESONATOR

The proposed crossed resonator is shown in Figure 1. It constitutes a conventional half-wavelength resonator (Z, $\theta_0 = 90°$) with an open circuited stub (Z_2, θ_2) and a short circuited stub (Z_1, θ_1) loaded in the center. For design convenience, all the stubs have the same characteristic impedance ($Z_1 = Z_2 = Z = 1/Y$). To obtain the first three resonance frequencies (f_1, f_2, f_3) of the crossed resonator, the input impedance of the crossed resonator can be calculated as follow.

$$Y_{in} = jY \frac{2\tan\theta_0 + \tan\theta_2 - \cot\theta_1}{1 - \tan\theta_0(2\tan\theta_0 + \tan\theta_2 - \cot\theta_1)} \tag{1}$$

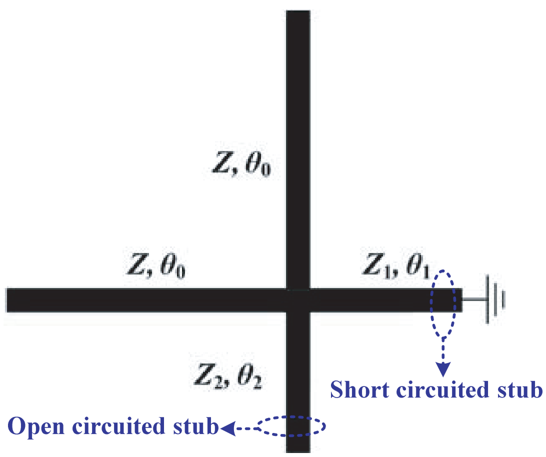


Figure 1. Structure of the proposed crossed resonator.

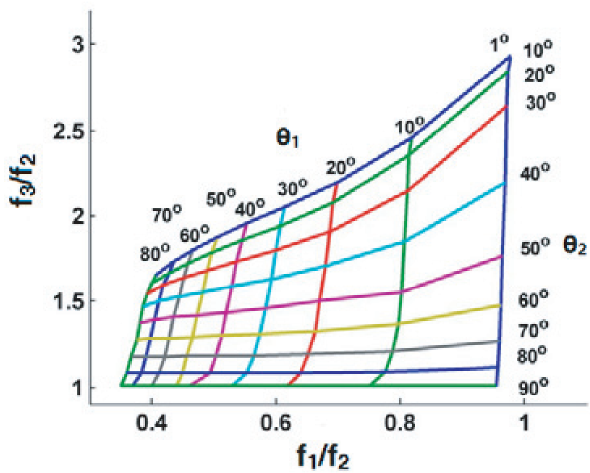


Figure 2. Design curve for crossed resonator.

When θ=90°,

$$Y_{in} = \lim_{\theta\to 90°} jY \frac{2\tan\theta + \tan\theta_2 - \cot\theta_1}{1 - \tan\theta(2\tan\theta + \tan\theta_2 - \cot\theta_1)} = 0 \tag{2}$$

And this corresponding frequency has been proved to be the second resonant frequency (f_2) of the crossed resonator [8]. The design curve for the other two resonance frequencies (f_1, f_3) can be plotted according to (1), which is shown in Figure 2. When the resonance characteristic of the central resonator is fixed, the frequency rates of first and third resonance frequency to second resonance frequency can be adjusted easily by changing the length of the short circuited stub and open circuited stub. By tuning the short circuited stub length from 1° to 80°, f_1/f_2 can varies from 0.97 to 0.35, while f_3/f_2 has a tuning range from 2.8 to 1.01 when the open stub varies from 10° to 90°. Therefore, the crossed resonator can be used as a common resonator of the triplexer. In the following design, three resonance frequencies are selected as 2.4 GHz, 3.5 GHz and 5.2 GHz, respectively.

3. DESIGN OF THE TRIPLEXER USING COMMON CROSSED RESONATOR

To verify the application of crossed resonator in triplexer design, a triplexer using crossed resonator as a common resonator is designed and fabricated in this section.

Figure 3 illustrates the structure of the proposed triplexer. The triplexer in this paper is designed on a conventional substrate of thickness 0.8 mm, dielectric constant 2.55, and loss tangent 0.0029. The

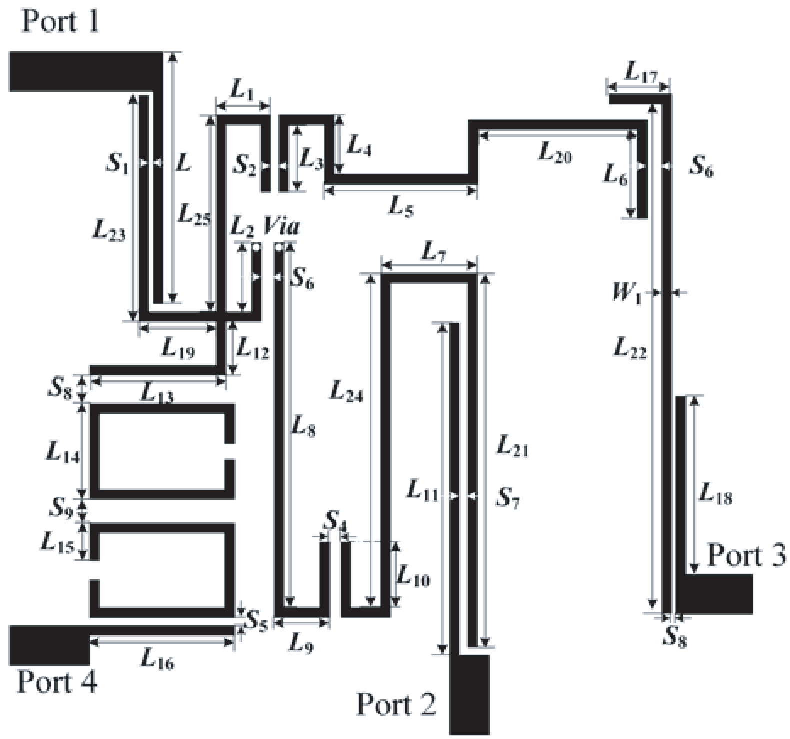


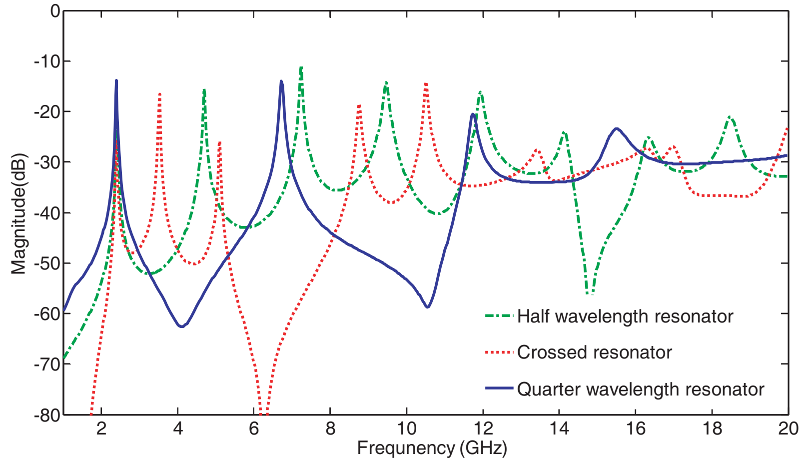
Figure 3. Layout of the triplexer using crossed resonator.

full wave simulation is carried out by Zeland IE3D. For the first bandpass channel, a quarter-wavelength uniform impedance resonator (UIR) and a half-wavelength UIR are coupled to the crossed resonator to obtain a wide stopband because of their well staggered high order resonance frequencies which will be mentioned below, where the via that connects the microstrip line, and the ground plane is denoted by a circle with a radius of 0.25 mm. Half-wavelength UIRs are involved to constitute the second bandpass channel. As for the third channel, open-loop UIRs are used to reduce the size.

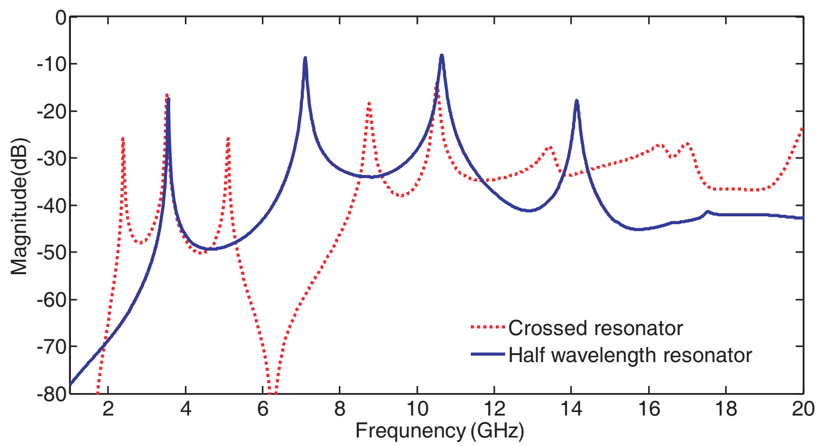
Here the first channel filter is presented for example to analyze the spurious frequencies suppression feature of the triplexer. The distributions of the resonance frequencies of the three different resonators are plotted in Figure 4(a). All the resonators have the same fundamental frequency at 2.4 GHz, which is the central frequency of the first passband. As can be observed, the spurious frequencies of the three different resonators stagger well. Therefore, an improved high frequency rejection level will be gained. For easy cation, only half-wavelength UIRs are coupled to the common crossed resonator to form the second and third channel filter to verify the proposed theory. As shown in Figure 4(b) and Figure 4(c), wide stopband responses will also be obtained for their staggered high order resonance frequencies in the other two channel filters.

The design procedure of each channel filter is similar to the conventional one, note that the coupling strength between input port (Port 1 in Figure 3) and the common resonator influence the external quality factors (Q_e) at all the three channels, which will lead to a limitation of realizable bandwidth of each channel. Figure 5 shows the extracted Q_e of different channels while L varies from 4.5 mm to 11 mm, where Q_{e1}, Q_{e2}, Q_{e3} are the external quality factors of the three channels respectively. Obviously, Q_{e2} is always smaller than Q_{e1} and Q_{e3}, which means that the bandwidth of the second channel will be wider than that of the first and third channel.

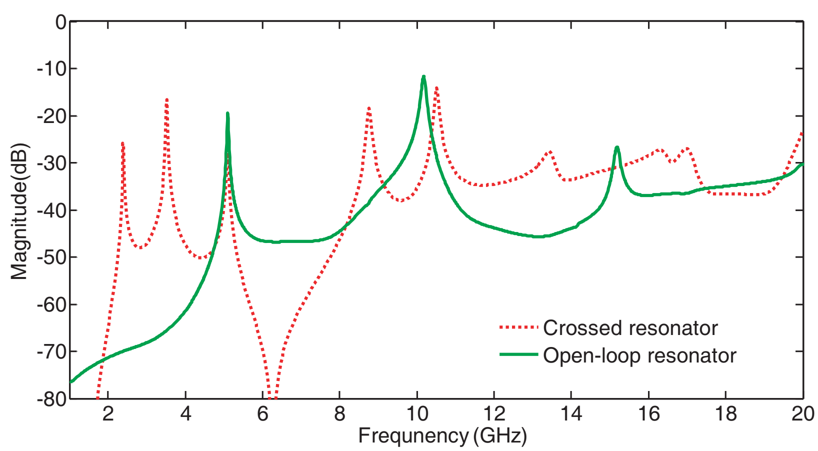
A triplexer is designed and fabricated for validation. The fractional bandwidths (0.04321 dB ripple level) of the three channels are selected to be 3%, 7% and 3%, respectively. The normalized elements in its respective three-order low-pass prototype are found as $g_0 = g_4 = 1$, $g_1 = g_3 = 0.8516$, $g_2 = 1.1032$. Based on the value of elements provided above, the designed coupling parameters of each channel filter in this proposed triplexer can be calculated. Take the first channel filter as an example, the coupling



(a)



(b)



(c)

Figure 4. S parameters of test resonators in different channel filters contrasting to the crossed resonator. (a) The first channel. (b) The second channel. (c) The third channel.

matrix can be given as

$$m_1 = \begin{bmatrix} 0 & 1.03 & 0 \\ 1.03 & 0 & 1.03 \\ 0 & 1.03 & 0 \end{bmatrix} \tag{3}$$

where the normalized coupling values m_{ij} in the synthesized coupling matrix $[m]$ are related to the physical coupling coefficients (k_{ij}) via [10]

$$k_{ij} = m_{ij} \cdot FBW \tag{4}$$

The external quality factors can be calculated as

$$Q_{e1} = \frac{g_0 \cdot g_1}{FBW} = \frac{g_3 \cdot g_4}{FBW} = 28.4 \tag{5}$$

where the FBW denotes the fractional band width.

According to Figure 5, we choose $L = 10.5$ mm for the required specifications. To get an appropriate coupling coefficient in each channel, the coupling property of the proposed crossed resonator is studied and analyzed. According to the analysis and Figure 2, the first resonant frequency is dominated by the short-circuited stub (θ_1), and the third one is determined by the open-circuited stub (θ_2). The current distribution of the crossed resonator at different frequency is plotted in Figure 6, which verifies above concept. With regard to the coupling property of the crossed resonator, the short-circuited stub (θ_1) is coupled to a quarter-wavelength resonator to realize the first channel, while the open-circuited stub (θ_2) is coupled to an open-loop resonator to realize the third channel and the central half-wavelength resonators (θ_0) is coupled to a half-wavelength resonator to realize the second channel. Common coupled lines are used to realize the non-adjacent coupling between resonators. The optimized parameters of the triplexer in Figure 3 are: $L = 10.50$, $L_1 = 2.71$, $L_2 = 1.77$, $L_3 = 3.40$, $L_4 = 3.00$, $L_5 = 7.69$, $L_6 = 4.50$, $L_7 = 4.86$, $L_8 = 16.62$, $L_9 = 2.78$, $L_{10} = 3.30$, $L_{11} = 16.69$, $L_{12} = 2.69$, $L_{13} = 6.34$, $L_{14} = 4.83$, $L_{15} = 1.90$, $L_{16} = 7.25$, $L_{17} = 3.15$, $L_{18} = 9.00$, $L_{19} = 3.87$, $L_{20} = 7.97$, $L_{21} = 18.80$, $L_{22} = 25.42$,

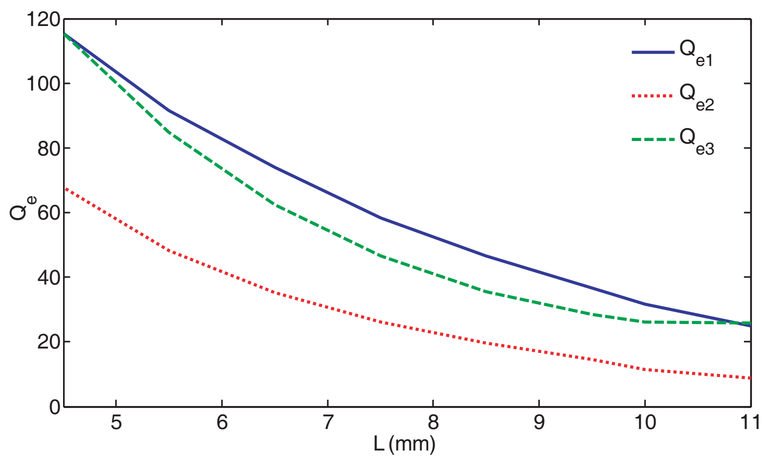


Figure 5. Extracted external quality factors at different frequencies.

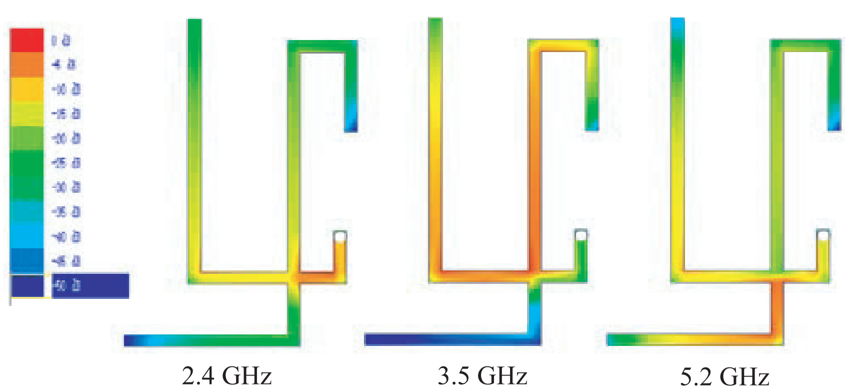


Figure 6. Current distribution at the first three resonance frequencies of the crossed resonator.

$L_{23} = 11.40$, $L_{24} = 16.78$, $L_{25} = 9.92$, $W_1 = 0.50$, $S_1 = 0.20$, $S_2 = 0.40$, $S_3 = 1.39$, $S_4 = 0.55$, $S_5 = 0.38$, $S_6 = 0.72$, $S_7 = 0.40$, $S_8 = 0.20$, $S_9 = 1.17$ (unit: mm).

Figure 7 shows the simulated and measured results of the triplexer while the measurement was carried out on HP 5320A vector network analyzer. The measured 3dB bandwidths of three channels

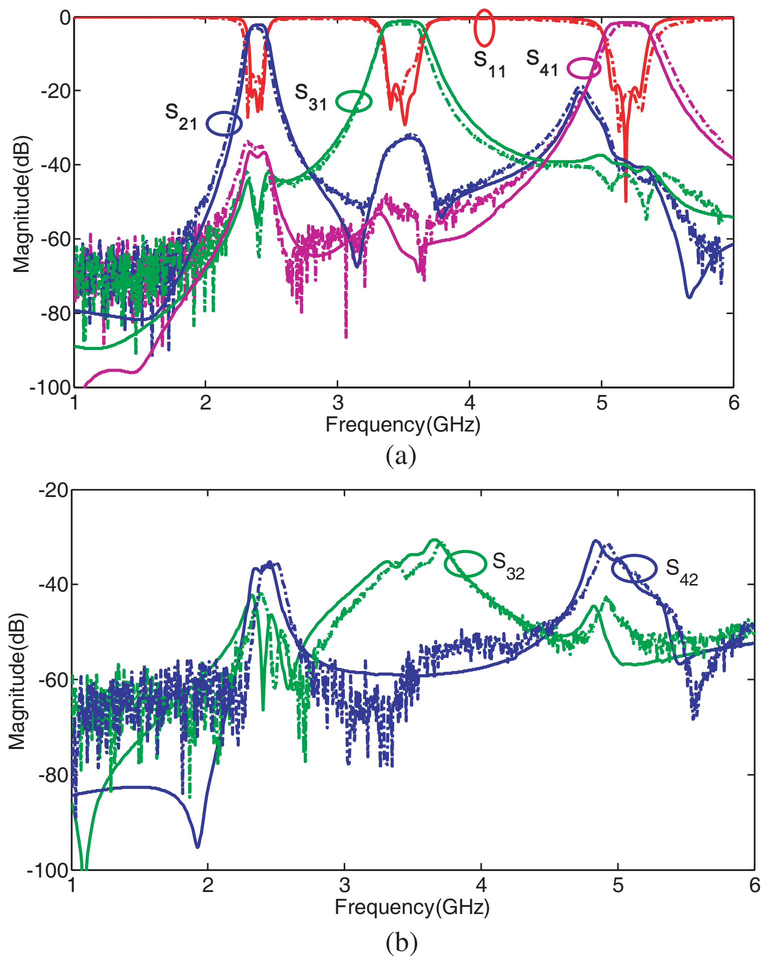


Figure 7. Simulated (solid line) and measured (dash line) S parameters of the triplexer. (a) S_{11}, S_{21}, S_{31}, S_{41}. (b) Isolations of the triplexer.

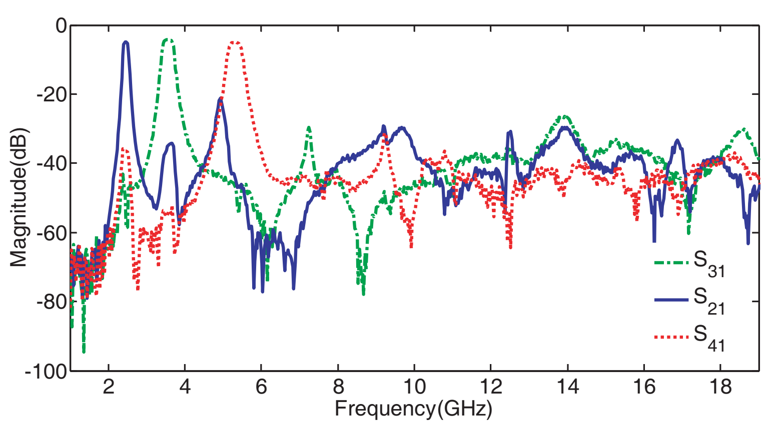


Figure 8. Measured wideband response of the triplexer.

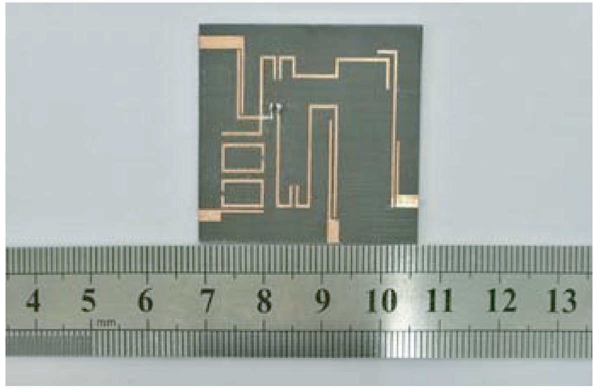


Figure 9. Photograph of the fabricated triplexer.

are 2.30 GHz to 2.45 GHz, 3.33 GHz to 3.64 GHz and 5.06 GHz to 5.43 GHz, respectively. The measured insertion losses are 2.42 dB, 1.62 dB, and 1.95 dB, respectively, while the measured passband return losses at all bands are below 15 dB and isolations are better than 30 dB between 1–6 GHz. Furthermore, the measured results of the wideband responses of the triplexer are shown in Figure 8. The proposed triplexer has a wide measured stopband suppression of 20 dB up to $8f_1$ where the f_1 is the central frequency of the first channel. Figure 9 presents a photograph of the fabricated triplexer. The size of the triplexer is 37.2 mm × 36.3 mm, approximately $0.41\lambda g \times 0.40\lambda g$, where the λg is the guided wavelength on the substrate at f_1. The measured results are in good agreement with the simulated ones.

4. CONCLUSION

This letter presents a novel triplexer using a common crossed resonator with a wide stopband. Appropriately adjusting the structure of the crossed resonator enables it to be shared by three channels. Moreover, a wide stopband can be observed as resonators with staggered spurious frequencies involved. For validation, a triplexer is designed, fabricated and measured. Good agreement between the simulated and measured results validates the performance of the proposed microstrip triplexer.

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