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NEW BANDPASS FILTERS USING HALF-WAVELENGTH AND BRANCH-LINE RESONATORS

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Abstract—New cross-coupled bandpass filters using half-wavelength ($\lambda/2$) and branch-line resonators are proposed. The branch-line resonators are made of two quarter-wavelength ($\lambda/4$) resonators in which a shorted circuit is realized by one open stub. In the first case, a non-0° feed structure at the input and output resonators is used to produce one pair of transmission zeros near the passband to improve the selectivity. In the second case, good selectivity and improved stopband rejection can be achieved at the same time by utilizing a 0° feed structure. Specifically, the proposed filters can simplify the manufacturing process of the conventional cross-coupled filters using $\lambda/2$ and $\lambda/4$ resonators without increasing circuit area significantly.

1. INTRODUCTION

Bandpass filters with good selectivity and stopband rejection are quite important in microwave communication systems. To improve selectivity, many cross-coupled filters using $\lambda/2$ resonators were presented in [1–11]. Besides, cross-coupled filters using $\lambda/4$ resonators [12–14] were proposed to diminish the circuit area. In order to decrease the vias in $\lambda/4$ microstrip coupled-resonator filters, the cross-coupled filters using both $\lambda/2$ and $\lambda/4$ resonators were proposed in [15]. Furthermore, broadside-coupled bandpass filters using both microstrip and coplanar-waveguide (CPW) resonators [16] can avoid via in [15] and the bond-wire bridges in conventional CPW process. Besides, the magnetic coupling constraint in the conventional

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cross-coupled filters [1–5, 7, 12–14] can be relaxed in [15] and [16] by adjusting the shorted circuit between two $\lambda/4$ resonators. However, the structures in [16] may suffer from package problems which may degrade the filter performance due to the open slots on the ground plane in practical use.

In this paper, a new microstrip filter using $\lambda/2$ and branch-line resonators is presented and implemented. The role of open stub in the proposed branch-line resonators is similar to the tapped stub between two $\lambda/4$ resonators in [17], which can provide a shorted circuit between two $\lambda/4$ resonators. With non-0° feed structure at the input and output ports, the new compact filter has the similar quasi-elliptic responses in [15] and [16] but doesn't require to consider the process problems, i.e., the fabrications of via in [15] and ground plane slots in [16]. Besides, this paper also uses the 0° feed structure [4] and [6] to verify the different feed type from [15] and [16], which can create extra two transmission zeros compared with the proposed non-0° feed filter.

2. DESIGN OF THE NON-0° FEED FILTER USING HALF-WAVELENGTH AND BRANCH-LINE RESONATORS

The microstrip cross-coupled filter using both $\lambda/2$ and $\lambda/4$ resonators, as suggested by [15] and [16], is shown in Fig. 1(a). Resonators 1 and 4 are composed of the $\lambda/2$ uniform-impedance resonators, and resonators 2 and 3 are consisted of the $\lambda/4$ uniform-impedance resonators, wherein a short circuit is realized by the grounding via. The equivalent circuit of Fig. 1(a) is demonstrated in Fig. 1(b), wherein the grounding via in Fig. 1(a) is replaced by an ideal shorted circuit in Fig. 1(b).

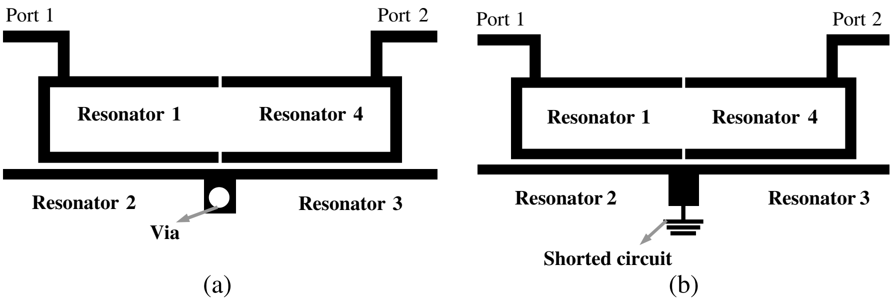

Figure 1. (a) Layout and (b) equivalent circuit of the fourth-order quasi-elliptic filter using both $\lambda/2$ and $\lambda/4$ microstrip resonators.

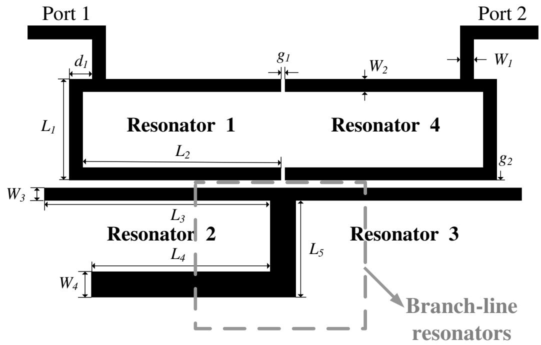

Figure 2. The layout of the proposed non-0° feed microstrip filter using $\lambda/2$ and branch-line resonators.

To avoid the fabrication of via in Fig. 1(a), a new type of microstrip cross-coupled filter using half-wavelength and branch-line resonators is proposed in Fig. 2. Here, two $\lambda/2$ U-shaped uniform-impedance resonators 1 and 4 are designed near input and output ports, and an open stub between resonator 2 and resonator 3 (see Fig. 2) is introduced to realize a shorted circuit which can avoid the via manufacture in Fig. 1(a). In Fig. 2, the gap between resonators 1 and 2 realize the electrical coupling, an open stub shared by resonators 2 and 3 can be designed for the required magnitude coupling, and the mixed coupling is realized between resonators 1 and 2 or between resonators 3 and 4. Thus, a quasi-elliptic filter can be realized by the abovementioned three coupling coefficients.

The well-established procedures for quasi-elliptic filters [1] can be used to design the proposed filter (Fig. 2). In order to facilitate the design, three approximate coupling structures for the proposed filter in Fig. 2 may be described in Fig. 3. The design curve for the electric coupling coefficient is shown in Fig. 3(a).

Figure 3(b) shows the mixed coupling structure and the corresponding design curve, wherein the magnitude of coupling coefficient can be enhanced by decreasing the distance of d_2. Note that the resonator 2 in Fig. 3(b) using an ideal short at one end approximates the resonator 2 in Fig. 2, which can be equivalent to a $\lambda/4$ resonator. Besides, the design curve for the magnetic coupling structure is shown in Fig. 3(c). Specifically, the magnetic coupling strength can be adjusted by changing the length of the open stub shared by the resonators 2 and 3.

Finally, the external quality factors can be extracted by varying the position of feed line as shown in Fig. 4. As the mentioned above

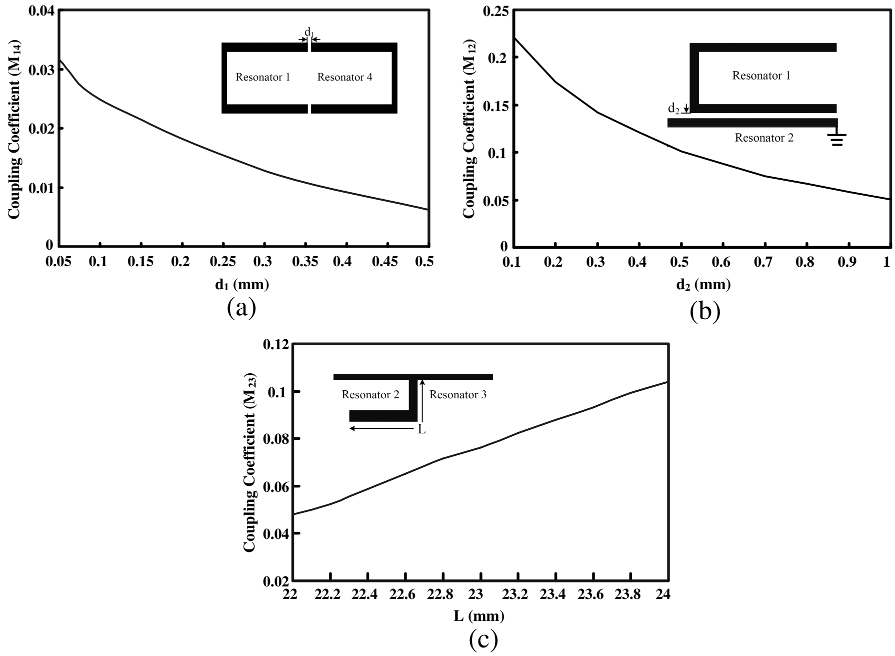

Figure 3. Approximate coupling structures and design curves for Fig. 2. (a) Electric coupling, (b) mixed coupling, (c) and magnetic coupling.

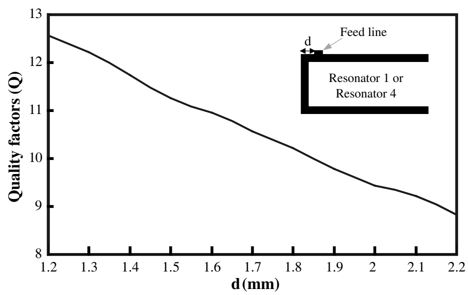

Figure 4. The design curve for the external quality factor.

(the initial design phase), the proposed filter is required to some fine-tuned process so as to adjust the responses back to the specification.

In this study, all of the filters are fabricated on a substrate with a relative dielectric constant of 3.55, a thickness of 0.508 mm, and a loss tangent of 0.0027. For demonstration, a microstrip filter with a fourth-order quasi-elliptic response is implemented and shown in Fig. 2. Since the cross-coupled and non-0° feed structures [4] and [6] are utilized, a single pair of transmission zeros around passband can be introduced to improve the selectivity. The center frequency and 3-dB fractional bandwidth of the proposed filter are 2.4 GHz and 10%, respectively. Consequently, the corresponding external quality factors and coupling coefficients are obtained as

$$M_{12} = M_{34} = 0.0856$$
$$M_{23} = 0.0786$$
$$M_{14} = -0.0219$$
$$Q_1 = Q_4 = 9.5974$$

where M_{ij} is the coupling coefficient between resonators i and j. The Q_1 and Q_4 are the external quality factors. Fig. 2 is the layout of the filter. The detailed dimensions are as follows: $L_1 = 7.7$ mm, $L_2 = 15.1$ mm, $L_3 = 17.2$ mm, $L_4 = 13.6$ mm, $L_5 = 7.4$ mm, $W_1 = 1.1$ mm, $W_2 = 1$ mm, $W_3 = 1$ mm, $W_4 = 2$ mm, $g_1 = 0.3$ mm, $g_2 = 0.55$ mm, and $d_1 = 1.7$ mm. The filter (Fig. 2) has a size of 36.4 mm × 16.65 mm. The measured and simulated results of the implemented filter are shown in Fig. 5. The measured center frequency is at 2.41 GHz, the minimum insertion loss is 1.66 dB, and the 3-dB fractional bandwidth is 9.5%.

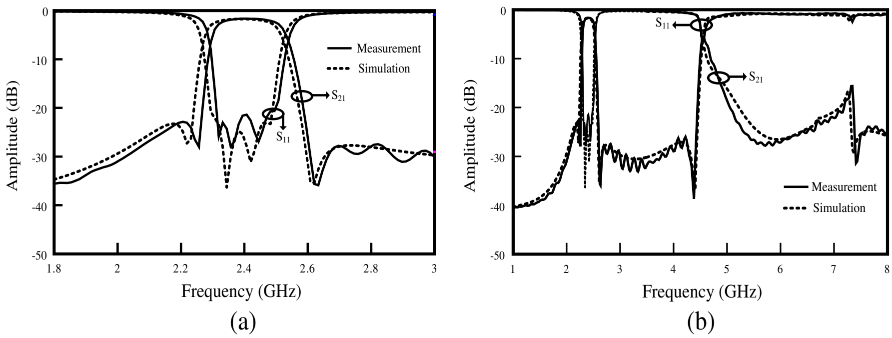

Figure 5. Measured and simulated results of the proposed non-0° feed microstrip filter. (a) Narrowband and (b) wideband frequency responses.

To improve the rejection level of the stopband, a new filter structure with four transmission zeros will be presented in the next section.

3. DESIGN OF THE 0° FEED FILTER USING HALF-WAVELENGTH AND BRANCH-LINE RESONATORS

In order to achieve good selectivity and stopband rejection, the 0° feed structure [4] and [6] can be used to implement the input and output ports of the filter. By replacing the non-0° feed structure in Fig. 2 by 0° feed structure, the filter having two additional transmission zeros in the stopband can be produced. Furthermore, the branch-line resonators can be arranged inside the two $\lambda/2$ resonators to diminish the total circuit area. The design procedure is similar to the non-0° feed structure in Section 2. The main different is the feed location of the resonators 1 and 4 near the input and output ports. In 0° feed structure, the feed points near the input and output ports are at the opposite locations about the center of the $\lambda/2$ resonators. Fig. 6 shows the layout of the proposed 0° feed compact filter. The center frequency and 3-dB fractional bandwidth of the proposed filter are 2.4 GHz and 5%, respectively. For the given specifications, the required coupling coefficients and the external quality factors can be obtained as follows:

$$\begin{aligned} M_{12} &= M_{34} = 0.0428 \\ M_{23} &= 0.0393 \\ M_{14} &= -0.0109 \\ Q_1 &= Q_4 = 19.1948. \end{aligned}$$

The detailed dimensions are: $L_1 = 1.1\,\text{mm}$, $L_2 = 9.7\,\text{mm}$, $L_3 = 19.6\,\text{mm}$, $L_4 = 18.6\,\text{mm}$, $L_5 = 4\,\text{mm}$, $L_6 = 17.1\,\text{mm}$, $L_7 = 8.3\,\text{mm}$, $W_1 = 1\,\text{mm}$, $W_2 = 1.1\,\text{mm}$, $W_3 = 2\,\text{mm}$, $W_4 = 1\,\text{mm}$, $g_1 = 0.3\,\text{mm}$, $g_2 = 0.31\,\text{mm}$, $d_1 = 6.2\,\text{mm}$, and $d_2 = 1.5\,\text{mm}$. The filter (Fig. 6) has a size of $41.5\,\text{mm} \times 10.8\,\text{mm}$. The measured and simulated results of the implemented filter are shown in Fig. 7. The measured center frequency is at 2.4 GHz, the minimum insertion loss is 2.52 dB, and the 3-dB fractional bandwidth is 5.2%. Obviously, there are four transmission

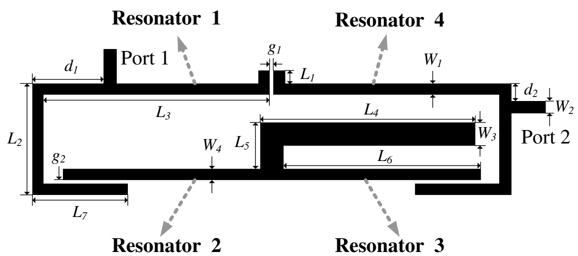

Figure 6. The layout of the proposed 0° feed microstrip filter using $\lambda/2$ and branch-line resonators.

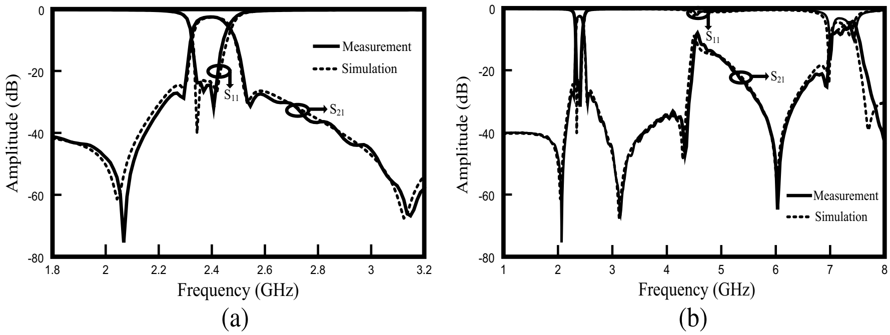

Figure 7. Measured and simulated results of the proposed 0° feed microstrip filter. (a) Narrowband and (b) wideband frequency responses.

zeros in both sides of the passband, which is resulted from the 0° feed structure. The four transmission zeros can improve the selectivity and stopband rejection at the same time.

Note that the transmission zero around 4.5 GHz is caused by the cross coupling. Thus, the frequency of the zero may be changed by adjusting the strength of the electric coupling.

4. CONCLUSION

In this paper, two new microstrip bandpass filters using $\lambda/2$ and branch-line resonators have been presented. The first filter structure utilizes only one open stub to realize similar passband response of filters which utilize both $\lambda/2$ and $\lambda/4$ resonators without a significant increment in circuit size. By changing the feed structure of the first filter, a filter with improved stopband rejection has also been realized, which can create four transmission zeros in both sides of the passband. Specifically, the second filter has a compact size due to that the branch-line resonators are placed inside the two $\lambda/2$ resonators to achieve further circuit area reduction.

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