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A Dual-Band Bandpass Filter Using a Single Dual-Mode Ring Resonator

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Abstract—A simple microstrip ring-resonator is presented for novel design of dual-band dual-mode bandpass filters with good isolation and upper-stopband performance. By increasing the length of the loaded open-circuited stub, the two first-order degenerate modes are excited and used for the first passband, while one of the third-order degenerate modes moves downward and forms the second passband together with a second-order degenerate mode. Meanwhile, three transmission zeros are properly tuned for the rejections between the two passbands and in the upper stopband. After installing two coupled-line sections on a square ring at the two ports with 90°-separation, a dual-band filter with the two transmission poles in each passband is designed and measured. Without adding any additional perturbation element inside the ring, the measured filter shows good performance for both in-band matching and outside rejections of the desired dual passbands.

Index Terms—Bandpass filter (BPF), dual-mode dual-band, isolation, ring resonator, transmission zeros.

I. INTRODUCTION

MICROSTRIP ring resonators have been widely used for applications in planar circuits, such as filters, antennas and other microwave components [1]. Because of the coexisting of the two degenerate orthogonal modes, a ring resonator owns the advantages of compact size and high-quality (Q) factor. For the dual-band applications using the dual-mode ring resonator, one of the most important issues is how to excite two degenerate modes and generate two transmission poles with a single resonator in each passband [2]. By using the stepped-impedance topology with a variable impedance ratio, the resonant frequencies of the ring resonator become adjustable [3]. However, only a single transmission pole was created in the second passband because of the symmetrical topology at the second-order resonance. To overcome this issue, two dissimilar ring resonators with different first-order resonant frequencies were directly combined together to achieve the desired dual-passband performance [4], [5]. Deposition of the increasing size, a complex feeding structure was usually required to be installed at the different layers [6], [7].

Recently, a class of dual-mode dual-band bandpass filters (BPFs) based on a single ring resonator were designed in [2], [8]. Instead of a common two-port excitation angle, i.e., either 90° or 180°, the two excitation ports were placed at 45° or 135°-separation. In [2], the two pairs of the first- and second-order degenerate modes of the ring resonator were excited and utilized to form two passbands individually, while the first- and third-order degenerate modes could also be utilized by installing two additional impedance transformers [8]. A class of dual-mode dual-band ring resonator BPFs using microwave C-sections was recently reported in [9], where the first- and second-order degenerate modes could also be excited by selecting the excitation angle as 60°. Nevertheless, these structures also need many perturbation elements to be installed along the ring.

In this letter, two coupled-line sections are simply installed on a single ring resonator at the two ports with 90°-separation. We could see that the two first-order degenerate modes are excited to form the first passband with two transmission poles, while the second passband is also constructed with two poles. In this case, the second-order degenerate modes cannot be disturbed and split with orthogonal feeding [2], [3]. Fortunately, one of the third-order degenerate modes can be dropped down by attaching the coupled-line section and utilized to produce another transmission pole at the second passband. As shown in Fig. 1, the two transmission poles can be easily generated in each passband by selecting the suitable length ($L_w$) of the attached line section. With the help of the coupled-line section, three transmission zeros will also be produced and controlled to provide a good isolation and wide upper stopband. A dual-band filter is then designed and measured to demonstrate the good in-band matching and the good rejections outside the desired dual passbands.

II. RING RESONATORS WITH COUPLED LINES

Fig. 1 shows the schematic and its equivalent even- and odd-mode resonant circuits for the proposed dual-band ring resonator BPF. It consists of a single resonator and two identified coupled-line sections. Based on the even-odd mode analysis under the weak coupling [2], the symmetrical plane in Fig. 1(a) becomes the perfect magnetic wall and electric wall, respectively. $Y_f$ and $Y_p^{eo}$ represent the two input admittances at two ports, looking into the left and right sides of the one-port bisection network, which is a one-port network with open- and short-circuited ends in the plane of symmetry accordingly, as shown in Fig. 1(b) and 1(c). $Y_n$ and $\theta_n$ are the characteristic admittance and the electrical length of the loaded open-circuited stub on the ring. According to the transverse resonance
technique, all the resonant frequencies under the even- 
and odd-mode excitation satisfy [2]

$$\text{Im}(Y_t + Y_r^e) = 0$$  \hspace{1cm} (1)
$$\text{Im}(Y_t + Y_r^o) = 0$$  \hspace{1cm} (2)

where

$$Y_t = jY_s \tan \theta_s$$  \hspace{1cm} (3)
$$Y_r^e = jY_r \left( \tan \frac{\theta_1}{2} + \tan \frac{\theta_2}{2} \right)$$  \hspace{1cm} (4)
$$Y_r^o = -jY_r \left( \cot \frac{\theta_1}{2} + \cot \frac{\theta_2}{2} \right).$$  \hspace{1cm} (5)

Due to the transversal interference between the two signal paths 
from one port to the other port, as discussed in [10], the 
transmission zeros in this case ($\theta_2 = 30^\circ$) appear at 

$$\theta_1 = 2(n + 1) \times 90^\circ, \hspace{0.5cm} n = 0, 1, 2, \ldots$$  \hspace{1cm} (6)

However, the line dispersion and the parasitic effects of 
discontinuities also impact the exact locations of the frequencies 
of these transmission poles and zeros. Fig. 2 plots the five transmission 
pole frequencies ($f_i$, $i = 1, 2, 3, 4, & 5$) and two transmission zero frequencies ($f_z$) versus the line length ($L_s$), as shown in Fig. 1(a). It can be seen that all the transmission pole frequencies 
become smaller as $L_s$ increases. Note that the first two resonances 
at $f_1$ and $f_2$, coalesce initially and split from each other 
as $L_s$ increases from 2 to 9 mm. It implies that the first-order degenerate modes are slit and the two transmission poles in the first 
desired passband around 2.3 GHz become possible as $L_s$ extends. 
The fourth resonance, $f_4$, shifts down quickly and builds up 
the second passband together with the third resonance ($f_3$) 
around 4.0 GHz. Fig. 3 shows the frequency responses of the 
ring resonator under a weak coupling. While the line 
length $L_s$ increases from 6 to 8.8 mm, the third and fourth resonances 
($f_3$ and $f_4$) further move close to each other and thus 
form a second passband, which has a similar bandwidth and 
 quasi-symmetrical responses as the first passband. In particular, 
the fifth resonance ($f_5$) becomes the first harmonic frequency of 
this dual-band filter, which is very close to the transmission zero frequency of the coupled-line section [11]. By slightly adjusting the two gap distances ($g_1$ and $g_2$) as shown in Fig. 1(a), this additional transmission zero can be varied and utilized to suppress the harmonic frequency at $f_5$. Different from the work in [2], 
[8], [9], the second passband in this work is constructed by a second-order degenerate mode at $f_3$ and one of the third-order degenerate modes at $f_4$. In addition, two transmission zeros are always located between two desired passbands, thus providing a good isolation. On the other hand, one of the open-ends of the 
coupled-line section, as shown in Fig. 1(a), is arranged close to 
the ring resonator with a small gap ($g_1$), which can be considered 
as an additional perturbation to the transversal interference 
between two signal paths [10]. Hence, the distance between 
zeros can be adjusted, as shown in Fig. 4. As $g_1$ is increased 
from 0.1, 0.6 to 1.0 mm, the rejection level increases from 32, 
40 to 44 dB due to the shrunken distance between zeros.

III. EXPERIMENTAL RESULTS

To provide verification on the above proposed structure, a 
prototype filter circuit is designed and optimized with dual 
passbands at 2.3 and 4.1 GHz in a full-wave electromagnetic
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