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<tr>
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<tr>
<td><strong>Citation</strong></td>
<td>The 2012 IEEE International Microwave Symposium (MTT-S), Montreal, QC., 17-22 June 2012. In IEEE - MTTS International Microwave Symposium Digest, 2012</td>
</tr>
<tr>
<td><strong>Issued Date</strong></td>
<td>2012</td>
</tr>
<tr>
<td><strong>URL</strong></td>
<td><a href="http://hdl.handle.net/10722/165300">http://hdl.handle.net/10722/165300</a></td>
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Miniaturized Dual-Band Bandpass Filter Using $\lambda/2$ Spiral-Resonator and Loaded Open-Stub

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Abstract—In this paper, a miniaturized dual-band bandpass filter using the half-wavelength ($\lambda/2$) spiral-resonators and loaded open-stubs with a spiral-coupled scheme is proposed. The mechanism of the dual-band operation is shown as follows. The first passband resonance is employed by the fundamental resonant-mode (i.e., $f_1$) of the $\lambda/2$ spiral-resonator. Meanwhile, the loading effect introduced by the loaded open-stub could shift the first-spurious (i.e., $f_2$) of the $\lambda/2$ spiral-resonator downward, which leads to a finely adjusted second passband resonance. Then, based on the $\lambda/2$ spiral-resonators with loaded open-stubs mentioned above, the spiral-coupled scheme is implemented, which employs a strong enough passband enhancement around the dual-resonances to achieve the dual-band passband filter. Besides, the loaded-tapping scheme could produce five transmission zeros, which can not only enhance the dual-band passband selectivity, but also extend the upper stopband bandwidth with a good rejection level. To verify the mechanism above, a dual-band bandpass filter operated at 1.035 and 1.56 GHz is designed, implemented, and fabricated. A good agreement between the simulation and measurement is achieved.

Index Terms—Bandpass filter, dual-band, spiral-resonator, loaded open-stub, spiral-coupled scheme.

I. INTRODUCTION

Dual-band bandpass filter is one of the critical key components in the dual-band wireless communication system. Therefore, various structures have been developed to meet the ever-increasing practical application limits [1]-[10]. The dual-mode ring resonator with a compact size and easily adjusted dual-resonances has been widely employed for the dual-band bandpass filter design [2]-[4] with a relatively narrow upper stopband. To extend the upper stopband bandwidth of the dual-band bandpass filter, the stepped-impedance resonator (SIR) has been employed [5]-[8]. However, the sizes of these filters are relatively large. Recently, the embedded spiral resonator (ESR) [9], comb-loaded resonator [10], and circular cavity [11] are introduced to implement filters with good dual-band frequency responses. Nevertheless, the design of dual-band bandpass filter with good passband selectivity, wide stopband, and a compact size remains challenging.

In this paper, a dual-band bandpass filter with a competitive size is proposed. The bandpass filter consists of two half-wavelength ($\lambda/2$) spiral-resonators with loaded open-stubs, which are implemented with a spiral-coupled scheme. The dual-resonances (i.e., $f_1$ and $f_2$) are introduced by the $\lambda/2$ spiral-resonators with a loaded open-stub. Meanwhile, the spiral-coupled scheme is employed to achieve strong passband enhancement around the $f_1$ and $f_2$. Besides, five transmission zeros can be afforded by the loaded-tapping scheme, which can not only improve the passband selectivity, but also extend the upper stopband bandwidth with a good rejection level. The proposed filter with good frequency responses has a compact size as 35.96 mm $\times$ 18 mm (i.e., 0.160 $\lambda_9$ $\times$ 0.084 $\lambda_9$, where $\lambda_9$ is the microstrip guided wavelength on the substrate at the center frequency of 1.035 GHz).

II. SCHEMATIC AND OPERATION

Fig. 1 shows the layout of the dual-band bandpass filter. The filter consists of two $\lambda/2$ spiral-resonators (i.e., $Z_{\lambda/2}\theta_s$, where $\theta_s = \theta_{s1} + 2\theta_{s2}$) with loaded open-stubs (i.e., $Z_{\lambda/2}\theta_o$, $Z_0 = Z_s$), which are implemented as a spiral-coupled scheme [1]. Besides, to excite the filter, two 50$\Omega$ feed-lines are directly tapped to the $\lambda/2$ spiral-resonators, acting as the input/output (I/O) ports. To investigate the mechanism of the proposed scheme, the EM simulator IE3D and RT/5880 dielectric substrate with $\varepsilon_r$ of 2.2 and a thickness of 0.508 mm are used.

A. $\lambda/2$ Spiral-Resonator with Loaded Open-Stub

Fig. 2 depicts the simulated dual-resonances (i.e., $f_1$ and $f_2$) current density distribution of the $\lambda/2$ spiral-resonator with a loaded open-stub. As illustrated in Fig. 2(a), it is notable that the strong current density is distributed on the $\lambda/2$ spiral-resonators, which can allocate the $f_1$. Thus, from the resonant condition, the $f_1$ can be derived as

$$f_1 = \frac{c}{2(\ell_{s1} + 2\ell_{s2})\sqrt{\varepsilon_{eff}}}$$  (1)
where $l_{s1} + 2l_{s2}$ is the physical length of the $\lambda/2$ spiral-resonator, $c$ is the velocity of the light in free space, and $\varepsilon_{eff}$ is the efficient dielectric constant of the substrate. Besides, it can be seen that the current density is mainly concentrated on the $\lambda/2$ spiral-resonator and loaded open-stub, as depicted in Fig. 2(b). This means that the strong loading effect of the loaded open-stub could shift the first spurious $f_2$ of the $\lambda/2$ spiral-resonator downward, as shown in Fig. 3. It is seen that once the length $l_o$ of the loaded open-stub increases, the $f_2$ decreases. However, the variation of the $l_o$ has no effect on the $f_1$. Thus, it can be concluded that once the specific $f_1$ is fixed (i.e., the physical dimensions $l_{s1}$ and $l_{s2}$ are determined), the $f_2$ can be adjusted with a wide range by the loaded open-stub to meet the requirement of the dual-band operation.

**B. Spiral-Coupled Scheme**

The spiral-coupled scheme can afford strong enough passband enhancement around the dual-resonances (i.e., $f_1$ and $f_2$) [12]. As depicted in Fig. 2, it can be seen that the electric current density of the spiral-lines has an uniform concentration at the resonances. By making the width $w_s$ wider and gap $g_{s1}$ narrower, a smoother current distribution can be obtained. Therefore, the quality factor of the resonator could be improved with less conductor loss. As such, the ratio of the width $w_s$ to gap $g_{s1}$ in the $\lambda/2$ spiral-resonator is optimized and chosen as 2:1. Fig. 4 shows the loss responses of the proposed scheme. It can be seen that the conductor loss of the structure in both passbands is less than 0.155, which will lead to the competitively low passband insertion loss comparing to the patch scheme with low loss responses [13].

**C. Loaded-Tapping Scheme**

As shown in Fig. 5, the location of the tapped feed-line can determine the paths to allocate the transmission zeros (i.e., $f_{z1}$ and $f_{z2}$) around the first-resonance $f_1$, which enhance the first passband selectivity. The mechanism is studied as follow. The input equivalent admittances $Y_{ink} (k = 1$ and $2$) viewed from the tapping position to the open ends could be generated and calculated as

$$Y_{ink} = -jY_s \tan \beta l_k$$

where $Y_s$ is the characteristic admittances of the paths, and $l_k$ ($k = 1$ and $2$) is physical lengths of path $k$, respectively. Note that, the transmission zeros (i.e., $f_{z1}$ and $f_{z2}$) can be finely tuned while the electric lengths of each path correspond to a quarter-wavelength [1]. Meanwhile, as shown in Fig. 5(b), the current is distributed on the path 1 and path 2 of the upper $\lambda/2$ spiral-resonator with a loaded open-stub. This means resonance occurs and the signal cannot pass through it. Therefore, the transmission zero $f_{z3}$ is allocated when the
in both passbands, respectively. Besides, the filter can generate five transmission zeros (0.887, 1.198, 1.313, 1.666, and 2.469 GHz) in the stopband, which provide the wide stopband with a good rejection level and much improved passband selectivity. In addition, the proposed filter exhibits a compact circuit size as 35.96 mm × 18 mm (i.e., 0.160 λg × 0.084 λg), where λg is the microstrip guided wavelength on the substrate at the center frequency of 1.035 GHz.

III. CONCLUSION

In this paper, a compact dual-band bandpass filter is proposed based on the λ/2 spiral-resonators with loaded open-stubs, which can employ the finley adjusted dual-resonances. Meanwhile, the spiral-coupled scheme can introduce the strong enough dual-band passband enhancement around the dual-resonances. Besides, five transmission zeros are employed by the loaded-tapping scheme. These transmission zeros can not only improve the passband selectivity, but also extend the stopband bandwidth with a good rejection level. With good frequency performance and a compact size, the proposed filter is attractive to the dual-band wireless applications.

REFERENCES