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A NOVEL WIDEBAND BANDPASS FILTER USING STUB-LOADED RING RESONATOR AND TAPPED FEED

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Abstract—A compact wideband bandpass filter is proposed in this letter by means of short-circuited-stub loaded ring resonator and tapped feed lines. After the principle of an initial filter with wide operating bandwidth is described, a prototype filter with center frequency at 3.23 GHz and fractional bandwidth of 86.1% is designed and fabricated. Measured results well agree with the predicted ones, verifying the design principle.

1. INTRODUCTION

In recent years, wideband applications of communication systems have been promoting rapid development of various types of wideband bandpass filters (BPFs). Of them, the wideband BPFs [1–6] based on the concept of multiple-mode resonator (MMR) has been receiving widespread interests. An initial MMR with stepped-impedance configuration was originally reported in [1] to make use of its first three resonant modes in forming a BPF that covers the overall ultra-wideband (UWB) passband (3.1–10.6 GHz). Several other wideband BPFs based on varied MMR have been reportedly developed, such as stub-loaded resonator [2, 3], slot-line resonator [4], stepped-impedance CPW resonator [5], and so on. Among them, microstrip ring resonator has attracted much attention because of its compact size, high Q-factor and low radiation loss. So far, various ring-based BPFs have been developed for wideband application [6, 7].

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Generally speaking, it is always highly demanded that tight or strong coupling between the feed lines and the resonator should be realized in design of a wideband filter circuit. Many techniques [8, 9] have been reported using the two-layered structure to significantly enhance this concerned coupling strength, such as aperture-backed coupled lines [8] and broadside-coupled microstrip-to-coplanar-waveguide (CPW) transition [9]. However, the exact alignment of such a two-layer circuit is still a challenging problem in practical fabrication. Inter-digital coupling structures [10] on the single layer may achieve the strong coupling to a certain degree, but this approach requires extremely small gap and strip width along the coupling section, and it can not be accurately realized due to unexpected fabrication tolerance in etching process. On the other hand, the tapped or direct-connected feeding structure has been widely used in the design of various BPFs inclusive of a wideband BPF [11], but these BPFs suffer from poor DC suppression as demonstrated in [11].

In this letter, a microstrip short-circuited-stub loaded ring resonator (SCSL-RR) and tapped feed lines are utilized together to develop a novel compact wideband BPF. By attaching the two dissimilar short-circuited stubs to the uniform-impedance ring resonator (UI-RR), the three resonant modes are appropriately excited to form up a wide passband. In design, the first and the third resonant frequencies can be freely controlled by making the two short-circuited stubs dissimilar in length and width. These short-circuited stubs can also bring out excellent DC-choked property. In addition, two open-circuited stubs are introduced at the connection points between the UI-RR and the tapped feed lines, aiming to adjust or enhance the coupling strength as desired. These open-circuit stubs improve the upper stopband performance by introducing transmission zeros. After the mechanism of the proposed BPF is described, a compact, low-loss wideband BPF prototype is designed and fabricated. The measured results are found in good agreement with the predicted ones from the direct EM simulation.

2. PRINCIPLE AND DESIGN OF SCSL-RR BANDPASS FILTERS

Figure 1 depicts the schematic of the proposed microstrip short-circuited-stub loaded ring resonator (SCSL-RR) circuit under weak capacitive coupling at the two feed lines. Figures 2(a)–(c) plot the frequency responses of this resonator circuit via varied sizes of the short-circuited stubs. In our design, the filter is constructed on the

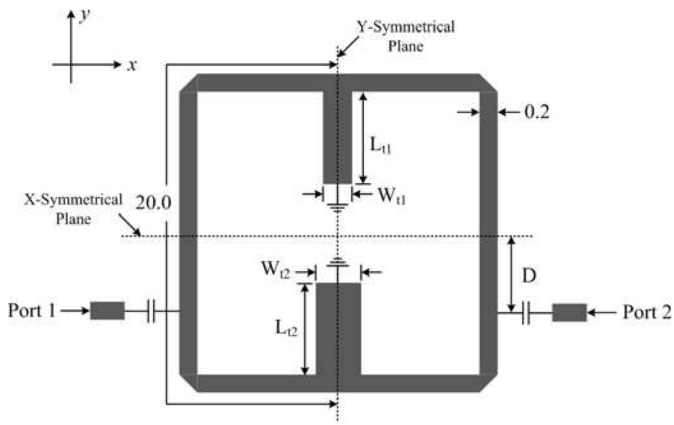


Figure 1. Schematic of the proposed SCSL-RR (unit: mm).

substrate with a relative permittivity $\varepsilon_r = 10.8$ and a thickness $h = 0.635$ mm. Initially, the sizes of the two short-circuited stubs are kept to be fixed, i.e., $L_{t1} = L_{t2}$, $W_{t1} = W_{t2}$. When the short-circuited stubs are properly installed on the Y-symmetrical plane of the ring resonator, an additional resonant mode can be produced at frequency lower than the 1st resonant mode of the uniform impedance ring resonator (UI-RR). This phenomenon can be seen from the dash line and dash dot line in Figure 2(a). Meanwhile, another resonant mode resonating at frequency higher than the 1st resonant mode of the UI-RR can be produced as the offset size, D, of the feeding position exceeds zero as shown by the solid line in Figure 2(a). Thus, it can be expected that the first three resonant modes can be used to make up a wide passband.

Figure 2(b) shows that the resonant frequencies of the 1st and the 3rd resonant modes can be tuned by the sizes of the short-circuited stubs. As the lengths of the stubs increase from 2.4 to 3.4 mm under the fixed stubs' widths of 0.4 mm, the 1st and the 3rd resonant frequencies move down to lower frequency band simultaneously while the 2nd resonant frequencies remain almost unaffected. Similarly, the 1st and the 3rd resonant frequencies move up to higher frequency band simultaneously as the widths of the stubs increase from 0.4 to 0.8 mm when the length of the stubs is fixed as 3.4 mm. Hence, it provides us with a degree of freedom to tune the 1st and the 3rd resonant frequencies. However, it is difficult to realize a wideband BPF with controllable bandwidth since the 1st and the 3rd resonant frequencies move down or up simultaneously as the sizes of the two short-circuited stubs are set to be the same.

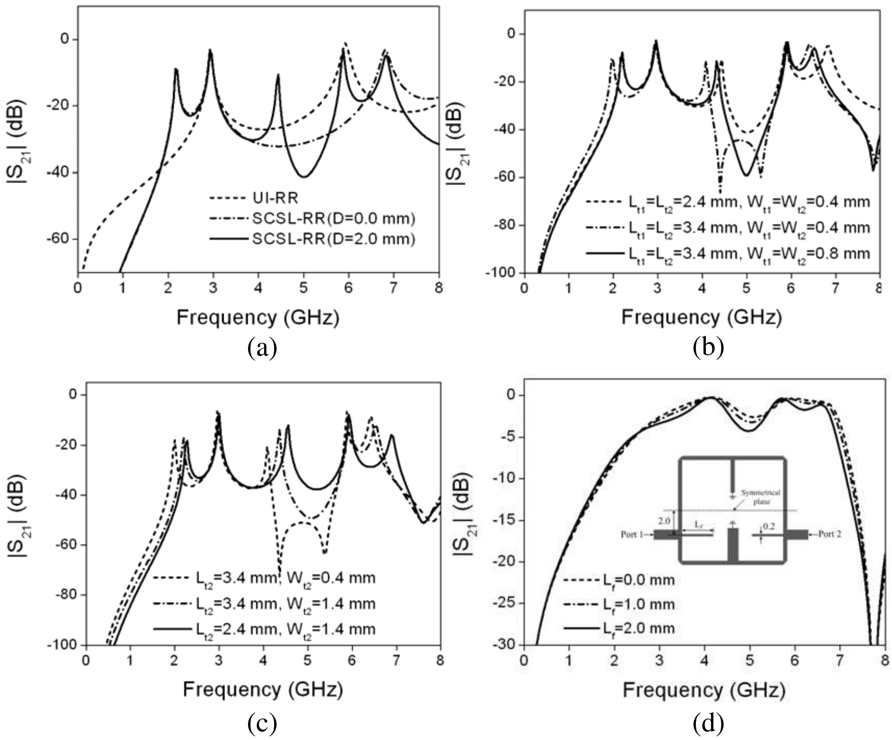


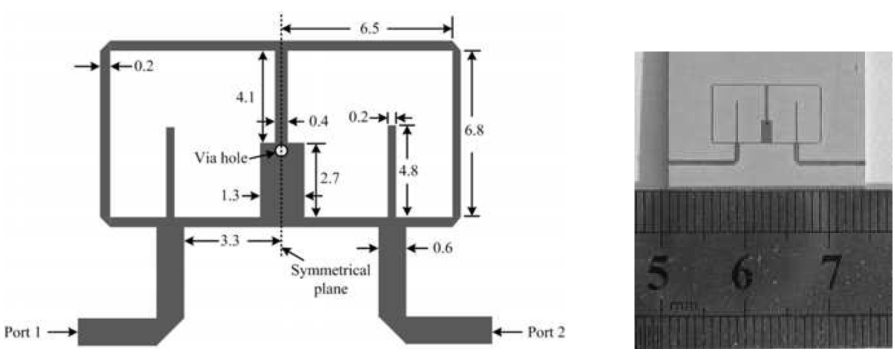
Figure 2. Frequency responses of the SCSL-RR circuit. (a) UI-RR and SCSL-RR. (b) Varied sizes of the two dissimilar stubs. (c) Varied sizes of one stub under $L_{t1} = 3.4\,\mathrm{mm}$ and $W_{t1} = 0.4\,\mathrm{mm}$. (d) Varied stub length, L_f, in connection to the two tapped feed lines (unit: mm).

In order to control the bandwidth effectively, the sizes of the two short-circuited stubs are no longer kept to be the same. The sizes of one stub remain unchanged ($L_{t1} = 3.4\,\mathrm{mm}$, $W_{t1} = 0.4\,\mathrm{mm}$), while the length ($L_{t2}$) and width ($W_{t2}$) of another stub are changed from 3.4 to 2.4 mm and 0.4 to 1.4 mm, respectively. As shown in Figure 2(c), the 3rd resonant frequency can be tremendously shifted up, while the first one slightly moves up. At the same time, the second resonant frequency is still kept unchanged almost. It hints that the bandwidths of the comprised passband can be determined or controlled by properly setting the sizes of the two short-circuited stubs to be unequal.

In order to design a wideband BPF with flat in-band response, tight coupling need to be realized at both feeder-line ports. In our design, the tapped feeding structure is implemented due to its advantages such as enhanced coupling strength and easy fabrication. Following the above description, we can understand that the feeding position should be fixed in order to excite the 3rd resonant mode at a specified frequency. In this way, the desired coupling strength between the resonator and feed lines can be not easily realized in a wide band covering the first three resonant frequencies. To facilitate this problem, the two identical open-circuited stubs are introduced in connection to the ring resonator at the same locations of the two feeding lines as shown in the inset of Figure 2(d). The coupling degree of concern can be now controlled by tuning the length of these two open-circuited stubs. As illustrated in Figure 2(d), the magnitude of $|S_{21}|$ decreases with the length of the open-circuited stub from 0 to 2.0 mm under the condition that other parameters are fixed, i.e., $L_{t1} = 3.4$ mm, $W_{t1} = 0.4$ mm, $L_{t2} = 3.4$ mm, $W_{t2} = 1.4$ mm, indicating that the coupling becomes weak gradually.

3. RESULTS AND DISCUSSION

Based on the above discussion, a wideband BPF is designed and implemented on the substrate Rogers 6010, with a relative dielectric constant of 10.8, thickness of 0.635 mm. Figure 3 shows the layout and photograph of the final prototype filter circuit. The filter occupies a compact circuit area of $7.2\times13.0\,\text{mm}^2$. Figure 4 plots the simulated and measured results. It can be observed that an additional transmission pole is introduced into the passband because of the two open-circuited stubs at two feeding points, which was purposely installed for adjusting



(a) (b)

Figure 3. Layout and photograph of the finally-implemented prototype wideband BPF. (a) Layout (unit: mm). (b) Photograph.

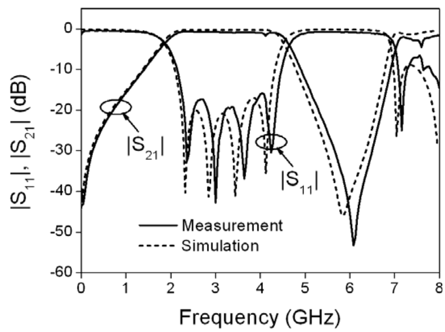


Figure 4. Simulated and measured results of the designed wideband BPF.

the coupling strength between the ports and resonator. Figure 4 shows that the measured results agree well with the simulated ones. The desired wide passband under the 3-dB definition is ranged from 1.84 to 4.62 GHz, indicating that its fractional bandwidth is around 86.1%. The measured insertion loss is 0.6 dB at minimum, while its respective return loss is better than 15.0 dB. One transmission zero is produced beyond the desired wide passband by the open-circuited stub, thus certainly improving the out-of-band performance.

Table 1. Comparison of various wideband bandpass filters.

	FBW	Size	$\|S_{21}\|_{\min}$
This work	86.1%	$0.36\lambda_0 \times 0.2\lambda_0$	0.6 dB
[1]	113%	$0.91\lambda_0 \times 0.06\lambda_0$	0.55 dB
[2]	109%	$0.62\lambda_0 \times 0.41\lambda_0$	0.4 dB
[3]	64%	$0.48\lambda_0 \times 0.11\lambda_0$	0.3 dB
[6]	68.2%	$0.49\lambda_0 \times 0.49\lambda_0$	0.7 dB

(FBW: the fractional bandwidth of passband; λ_0: the guide wavelength with respect to the central frequency of the passband; $|S_{21}|_{\min}$: the measured minimum insertion loss within the passband.)

4. CONCLUSION

In this letter, a novel SCSL-RR is proposed and adopted in the design of a wideband BPF. In principle, three resonant modes are realized by making use of the short-circuited stubs and the offset feeding method.

Our study shows that the fractional bandwidth of the desired passband can be freely controlled by designing the two short-circuited stubs in different sizes. By introducing the open-circuited stubs at the feeding points to form the tapped feed lines, the coupling degree between the ports and resonator can be properly adjusted and enhanced in order to achieve the flat in-band wideband frequency responses as expected. The measured results of the fabricated prototype filter are provided to verify the proposed method and validate the predicted results. Moreover, a table, namely Table 1, is tabulated to provide the performance of our proposed wideband BPF in comparison to those published ones, and it can demonstrate the advantage of our design, i.e., compact size.

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