

A NOVEL WIDEBANDBANDPASS FILTER USING TRIPLE-MODE SLOTLINE RING RESONATOR

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Abstract—A novel wideband bandpass filter on a triple-mode slotline ring resonator is proposed in this letter. By attaching two stubs with different lengths and/or widths to the symmetric plane of a slotline ring resonator, the frequencies of first three resonant modes can be rearranged towards quasi-equal separation. By feeding this slotline resonator using the microstrip feed lines at positions with an angle of 90° to the symmetrical plane, these three resonant modes can be simultaneously raised up, aiming to form up a wide passband. Meanwhile, a wide upper-stopband can be realized by setting the lengths of two stubs unequally. After the principle of an initial wideband filter is described, a prototype of compact filter with internally-loaded stubs is designed with fractional bandwidth of 66% at center frequency of 3.0 GHz. Measured results well validate the predicted ones.

1. INTRODUCTION

Microstrip ring resonator has been continuously receiving wide applications in design of microwave circuits blocks, such as bandpass filters (BPFs), couplers and so on [1], due to its attractive features of compact size and relatively high Q factor. It is Wolff in 1972 who firstly reported the appropriate splitting of two degenerate modes on a ring resonator for filter design [2]. Since then, a variety of planar dual-mode ring-resonator BPF with narrow operating bandwidth of a few percentages have been well presented [3–10] by forming up different perturbation elements along or besides the symmetrical plane

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with respect to two external ports. Recently, a microstrip-line ring resonator with paired stubs is proposed and investigated in [11] to design a wideband BPF by making use of its first three resonant modes. Due to a deficiency of strength in capacitive coupling between the feedling-lines and ring, the triple-mode ring resonator fails to be applied for a bandpass filter with wide bandwidth. To circumvent this problem, the two interdigital coupled lines are introduced at two ports by externally adding two stubs on the ring. However, this approach causes some new problems, such as deformation of an original triple-mode resonator, uncontrollable tolerance in fabrication of small coupling gap, complexity in design and enlarged overall size.

In this letter, a novel wideband BPF based on a single slotline ring resonator with two dissimilar slotline stubs is proposed, and it is fed by the two microstrip feedlines at the 90° -separation for simultaneous excitation of the first three resonant modes without needing to deform the ring resonator as inquired in [11]. After working principle and design procedure of the proposed BPF are described using its equivalent transmission-line model, a compact wideband filter with internally-loaded stubs is designed and its prototype filter is then fabricated to provide an experimental validation on the predicted frequency response.

2. FILTER STRUCTURE AND DESIGN PROCEDURE

Figure 1(a) depicts the schematic of the proposed stub-loaded slotline ring resonator, where the Z_r and Z_s are the characteristic impedances

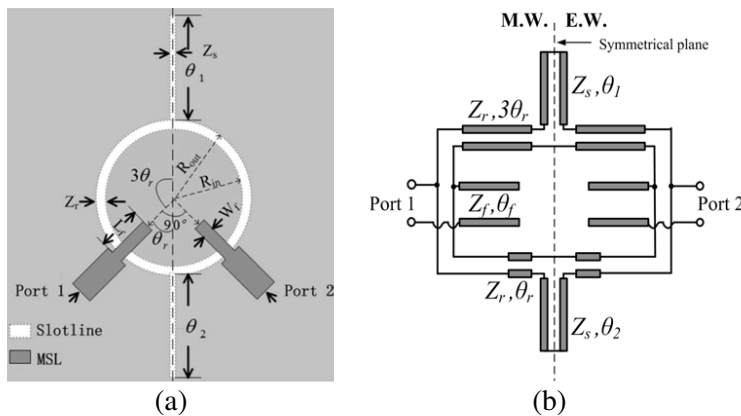


Figure 1. Proposed triple-mode slotline ring resonator with two loaded stubs. (a) Layout (unit: mm). (b) Equivalent transmission-line model.

of the slotline ring and two stubs, while the $8\theta_r$, θ_1 and θ_2 denote the effective electrical lengths of the ring resonator and two individual stubs, respectively.

Figure 2(a) illustrates calculated frequency responses of $|S_{21}|$ parameter using equivalent model in Fig. 1(b) under the condition of two identical stubs, i.e., $\theta_1 = \theta_2$. With no attached stubs or $\theta_1 = \theta_2 = 0$, only a single transmission pole emerges since the first even- and odd-mode resonate at the same frequency. As θ_1 and θ_2 increase to 30° and 60° , the first and second odd-mode resonant frequencies are both shifted downward but at different velocities while the first even-mode counterpart remains at 3.0 GHz. These three resonant modes will be simultaneously excited and utilized to form up a wide passband covering these three resonant frequencies.

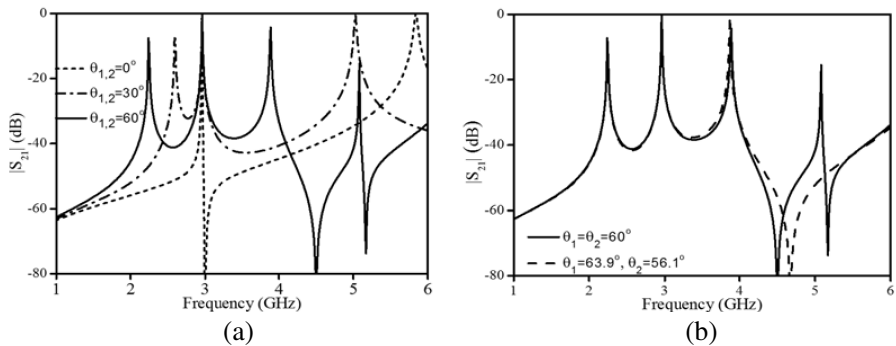


Figure 2. S -parameter versus electrical lengths of two slotline stubs at frequency 3.0 GHz under the fixed sum length of two slot stubs, $\theta_1 + \theta_2$. (a) $\theta_1 = \theta_2$, (b) $\theta_1 \neq \theta_2$.

In our design, the 2nd even-mode aims to be suppressed by signal cancellation in the upper and lower paths of the stub-loaded ring resonator with reference to Fig. 1. As can be seen from Fig. 2(a), the first and second odd-mode resonant frequencies tend to drop off so that further resonant modes can be quasi-equally spaced by reallocation and they can be simultaneously excited using the broadside coupled microstrip-to-slotline transition for realization of a flat frequency response over a wide range.

Equivalent transmission-line model of the BPF in Fig. 1(a) is given in Fig. 1(b). The central plane in Fig. 1(b) becomes perfect magnetic wall (M.W.) under the even-mode excitation and electric wall (E.W.) for odd-mode analysis, respectively. Thus, its bisection becomes a one-port network with short- and open-circuited ends at the central

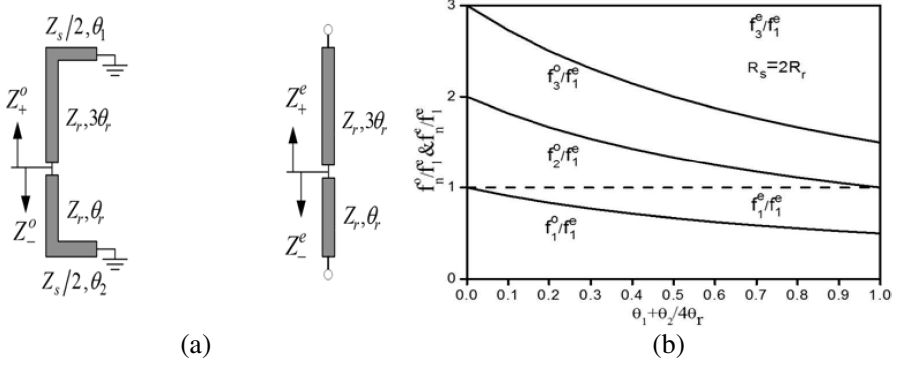


Figure 3. (a) Equivalent odd- and even-mode one-port bisection. (b) Normalized resonant frequencies versus electrical overall stub length where f_n^o and f_1^e represent the n th-order odd mode and the first-order even mode, respectively.

position, respectively. In Fig. 3(a), $Z_{+,-}^{e,o}$ represent the port impedance of the even- and odd-mode, looking into the up and down side. With the resonance condition of even and odd mode, i.e., $Z_+^e + Z_-^e = 0$ and $Z_+^o + Z_-^o = 0$, all the resonant frequencies can be simply determined.

In analysis, the ratio of characteristic impedances between slot stubs and ring resonator is set as R (odd mode), where $R = Z_s/2Z_r$. So, the impedance of the network under odd-mode excitation should be

$$Z_+^o + Z_-^o = jZ_r \frac{R(\tan \theta_1 + \tan \theta_2)(1 - \tan \theta_r \tan 3\theta_r)}{(1 - R \tan \theta_1 \tan 3\theta_r)(1 - R \tan \theta_2 \tan \theta_r)} + jZ_r \frac{(\tan \theta_r + \tan 3\theta_r)(1 - R^2 \tan \theta_1 \tan \theta_2)}{(1 - R \tan \theta_1 \tan 3\theta_r)(1 - R \tan \theta_2 \tan \theta_r)} \quad (1)$$

Similarly, the impedance for the even mode can be calculated as

$$Z_+^e + Z_-^e = -jZ_r \left[\frac{1}{\tan 3\theta_r} + \frac{1}{\tan \theta_r} \right] \quad (2)$$

For simplicity in analysis, the impedance ratio, R , is set to be one. In this aspect, the resonance condition can be established by assigning both port impedances, $Z_+^o + Z_-^o$ and $Z_+^e + Z_-^e$, as zero,

$$4\theta_r + \theta_1 + \theta_2 = n\pi \quad n = 1, 2, 3 \dots \quad (3)$$

$$4\theta_r = m\pi \quad m = 1, 2, 3 \dots \quad (4)$$

Assuming ω_n to be the resonant angular frequency of a ring without loaded-stubs, while $\Delta\omega_n$ denotes the frequency shift caused

by θ_1 and θ_2 . As such, the relationship among θ_1 , θ_2 , θ_r and $\Delta\omega_n$ can be found from the following equation.

$$\frac{\Delta\omega_n}{\omega_n} = -\frac{\theta_1 + \theta_2}{4\theta_r + \theta_1 + \theta_2} \quad n = 1, 2, 3 \dots \quad (5)$$

As θ_1 and θ_2 increase with the odd-mode resonant frequencies, the frequency difference is negative. Even though the shift in relative bandwidth is the same as θ_1 and θ_2 increase, the higher-order resonant modes move down in an accelerated velocity as the stub lengths increase. The relationship between the odd- and even-mode resonant frequencies can be derived as below, where f_n^o and f_n^e stand for the n th odd and even mode, respectively. Normalized frequency ratio of the odd resonant modes versus that of the first even resonant mode is plotted in Fig. 3(b), from which we can see that the odd modes shift down with the stub lengths.

$$\frac{f_n^o}{f_n^e} = \frac{1}{1 + \frac{\theta_1 + \theta_2}{4\theta_r}} \quad n = 1, 2, 3 \dots \quad (6)$$

In practical design, we find that one unwanted resonant mode, i.e., 3rd odd resonant mode, exists within the upper stopband as the electrical length of two slot stubs reaches 60° . In order to eliminate this harmful spurious harmonic without influencing the desired filtering performance with three poles in the passband, electrical lengths of two slot stubs are unequally or separately selected under the condition that the sum of them or the overall stub length remains unchanged. In this case, an out-of-phase phase difference between the upper and lower paths of the ring resonator in Fig. 1 can be achieved, so as to suppress this 3rd odd-mode harmonic while keeping three poles unchanged in the passband. As illustrated in Fig. 2(b), the 3rd odd-mode peak can be fully eliminated as θ_1 and θ_2 are set to two different phases, 63.9° and 53.1° , from the identical phase, 60° .

Then microstrip-to-slotline transition is brought in as coupling after the resonant modes have been designed and discussed above. As illustrated in Fig. 4, simulated $|S_{21}|$ magnitude of the frequency range covering the three resonant modes studied above vary under three different feedline lengths (L_f). The three resonant modes are observed under weak coupling when feedline lengths are 0.5 mm and their magnitude arise with increment of feedline lengths from 0.5 mm to 2.1 mm. When feedline lengths are set to be approximate a quarter wavelength of the chosen central frequency, a flat wideband passband covering the excited three resonant modes is formed.

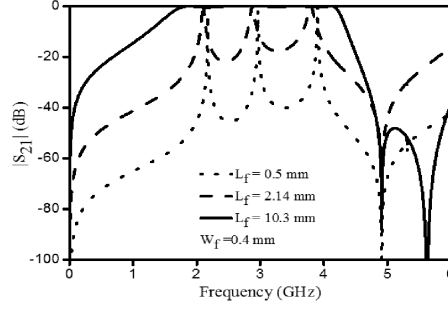


Figure 4. Simulated S -parameter with varied feedline lengths (L_f).

3. RESULTS AND DISCUSSIONS

Based on the above analysis, a triple-mode wideband BPF has been designed and fabricated on the substrate, namely, Rogers 6010, with the thickness of 1.27 mm and dielectric constant of 10.8. To achieve good impedance matching, the characteristic impedances of the feed line stubs and the ring resonator are chosen as $74\ \Omega$. Fig. 5(a) shows the layout of the designed filter circuit. Simulated results are obtained from the IE3D software and they are plotted together with the measured results. Measured results are found in good agreement with the simulated ones. The center frequency of the core passband is set as 3.0 GHz with a fractional bandwidth of 66.0%. Moreover, as can be seen in Fig. 5(b), both simulated and measured results show a wide

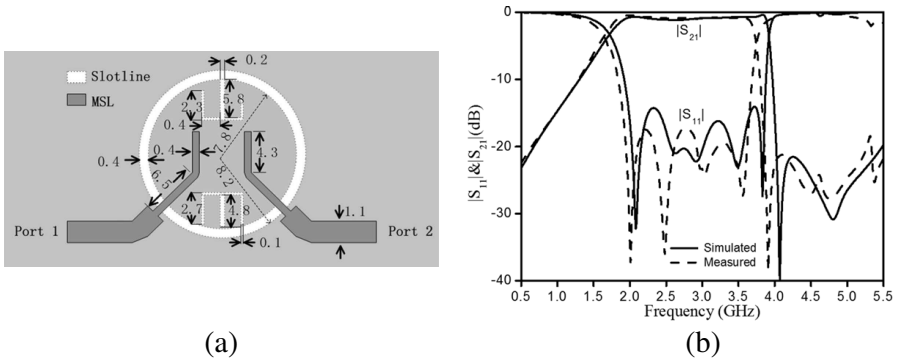


Figure 5. (a) Layout of the designed wideband filter with two internally loaded slotline stubs. (unit: mm). (b) Simulated and measured results.

upper stopband in a range from 4.0 to 5.5 GHz. It can be understood that the fourth resonant mode is satisfactorily suppressed while the two transmission zeros, generated by the ring resonator and feed line, can form up a wide upper stopband as expected.

4. CONCLUSION

This letter presents a triple-mode wideband bandpass filter on a single slotline ring resonator with attachment of the two unequal-length slot stubs. After the working principle and design procedure of the proposed bandpass filter are described via equivalent transmission-line model and even-odd mode analysis method, a wideband BPF with good out-of-band rejection is designed and fabricated. Good agreement between the measured and simulated results verifies well our design principle in experiment.

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