Miniaturized Microscript Bandpass Filter Based on the Twist Split Ring Resonators

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Abstract— In this paper, a novel design for miniaturized microscript bandpass filter based on the twist split ring resonators (TSRRs) is analyzed systematically. The proposed TSRRs printed on the conventional dielectric substrate with full size ground plane exhibit two resonance states separated each others. And the two resonance frequencies can be tuned by changing the distance between the two single split ring resonators. We first discuss the resonance characteristics and optimize the designed filter with finite element method based simulator (Ansoft HFSS V14). Then the designed microscript bandpass filter is fabricated by standard printed circuit board techniques. Finally, the proposed filters are numerically and experimentally discussed in details, including the passband, out-of-band suppression, and higher order properties. Both results show that the proposed filter exhibits a compact size and well passband characteristics, which can be used in radio frequency/microwave integrated circuits.

1. INTRODUCTION

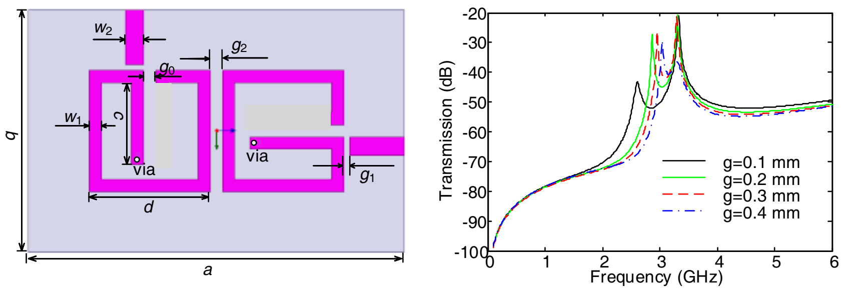
In the pase decade, artificial designer materials consisting of sub-wavelength-size periodic inclusions have attracted exciting attention since the first experimental realizations of such composite structure [1, 2]. Researchers called the composed structures as metamaterials [3] to reveal their unique electromagnetic properties, e.g., negative refraction [4], reversals of both Doppler shift and Cherenkov radiation [5], enhancement of evanescent wave and super-resolution imaging [6–8]. Recent years, thanks for the breakthroughes of the designs and characterizations of metamaterials and also the nano fabrications, it has found plentiful and important applications for the metamaterials in various areas with operating frequencies covering a wide spectra ranged from low-frequency (acoustic) and microwave through terahertz to even optical ranges [9–15]. Most of the applications, e.g., focused lens [9], absorbers/reflectors [10–13], cloaks [14] and sensing [15], are based on the macroscopic properties of bulk metamaterial configurations, such as negative refractions.

On the other hand, it has observed that metamaterial unit cells can also be used for some miniature applications requirements. Specifically, due to the resonance nature of most metamaterial unit cells, one can achieve miniaturized microwave components, e.g., the compact bandpass/notch filters [16–19] and antennas [20, 21]. However, most of the reported metamaterials inspired bandpass filters (we main discuss the novel filter application of metamaterials in this paper) as mentioned above still suffer from large inclusion sizes and complex configurations, which restrict the practical bulk RF/microwave circuit integration applications.

In this paper, based on the motivation of simplifying filter designs and fabrications, we propose a novel design for the miniaturized microscript bandpass filter by using the twist split ring resonators (TSRRs), which previously discussed at terahertz band and can possess magnetoinductive coupling effects. The magnetoinductive coupling effects can result in both magnetic and electronic resonances [22]. Here the TSRRs are designed on a conventional substrate and two metallic holes are used to connect the TSSRs with ground plane to achieve a miniaturized microscript bandpass filter. It will be seen that the proposed filter in this paper has a very simple inclusion and exhibits very will frequency selection characteristics.

2. RESONANCE CHARACTERISTICS

The configuration of the TSRRs used to characterize the resonances is shown in Fig. 1(a). Two metallic SRRs with 90° twist angle and closer arrangement are printed on the Rogers Ro4003 dielectric substrate (the relative dielectric constant is $\epsilon_r = 3.55$ and loss tangent is $\tan\delta = 0.0027$, and the thickness is 0.8 mm). The extend lines within the conventional SRRs connected with the ground plane through metallic holes are used to control the impedance when design the microscript fed filter. The backside of the substrate is full-sized metallic ground plane and the thicknesses of both the TSRRs and ground plane are 0.017 mm. As shown in Fig. 1(a), one gap is presented between each SRR and microscript feed line to show the coupling effects from microscript feed line to the twist SRR, so that the resonance characteristics of the TSRRs can be clearly obtained and analyzed [16].

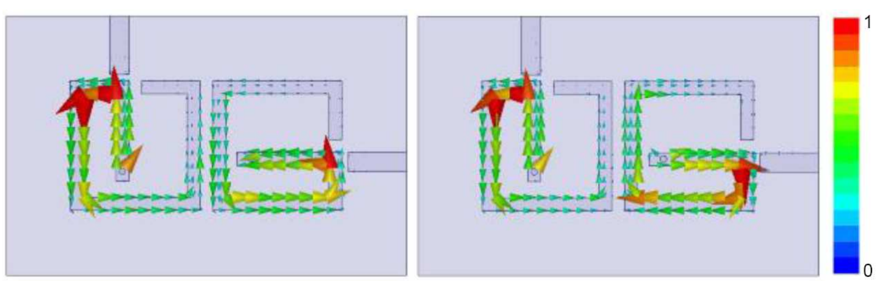


(a) (b)

Figure 1: (a) Schematic representation of the TSRRs resonator, and (b) simulated transmission properties at different space values.

The resonance characteristics of the proposed configuration are demonstrated by numerical simulations through ANSYS High Frequency Structure Simulator (HFSS) V14.0. To obtain the resonance frequencies within the S-band and based on above mentioned material parameter values, we get the following dimensional parameter values for the TSRRs, in millimeter: $a = 12.4$, $b = 8.0$, $c = 2.7$, $d = 4.0$, $w_1 = 0.4$, $w_2 = 0.6$, $g_0 = 0.4$, and $g_1 = 0.2$. To discuss the effect on the resonance frequency shift, we change the space values g_2 between the two twist SRRs from 0.1 mm to 0.4 mm. The simulated results are shown in Fig. 1(b). It clearly shows that for one of the space condition (for example, $g_2 = 0.4$ mm), there are two distinct transmission peaks corresponding to two different resonance states. As shown in Fig. 2, the surface current density characteristics at such two resonance frequencies indicate quite different orientations. For specifically, the current densities at the surface of the twist SRRs for first resonance frequency are the same orientations relating to magnetic resonance, and contrarily for the second resonance frequency opposite current orientations appears at the twist SRRs corresponding to electronic resonance. These results are similar to the reference [22].

Moreover, when decrease the space g_2 from 0.4 mm to 0.1 mm, the first resonance frequency shifts downward sharply and the second frequency shifts upward slightly. Therefore, to obtain a wide passband one should narrow the space between the twist SRRs. It should be noted that when further narrow the gap between the twist SRRs (or connect directly with each other), the two resonance frequencies will be separated far from each other and therefore the insert loss of the filter will be enlarged.



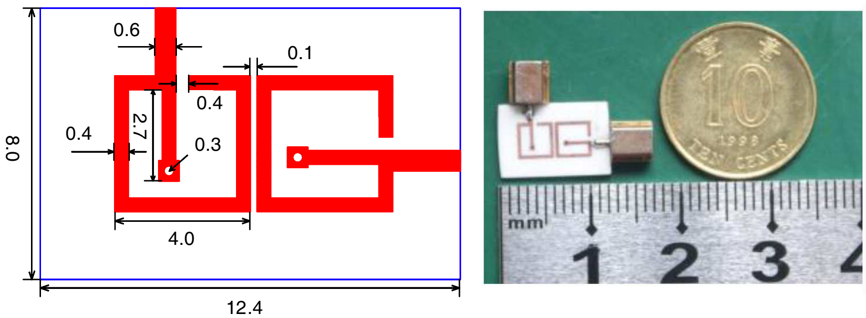
(a) (b)

Figure 2: Simulated current density characteristics at two resonance states.

3. FILTER FABRICATION AND CHARACTERISTICS

Based on the above analysis, the proposed miniaturized microscript bandpass filter configuration is shown Fig. 3(a) with dimensional parameters in millimeter. The microscript feed lines are directly connected with the TSRRs (the only difference compared with previous numerical investigations). Finally, the designed filter is fabricated by standard printed circuit board fabrication techniques, and two 50 Ohm micro-miniature coaxial connectors (operated from DC to 6 GHz) are soldered to the two feed lines of the compact filter, as shown in Fig. 3(b).

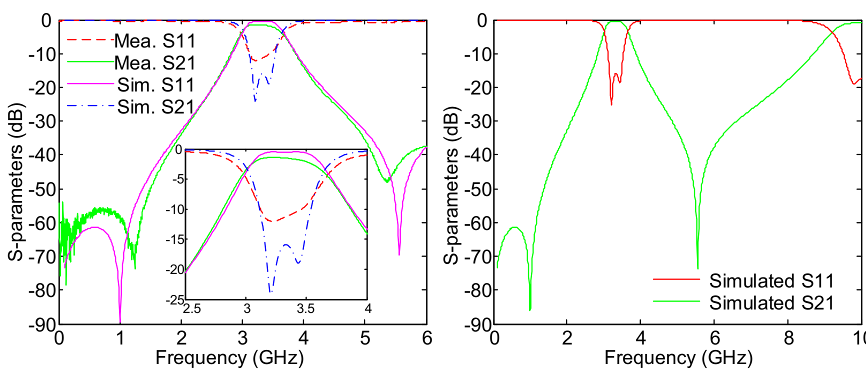
The transmission and reflection properties of the proposed miniaturized microscript bandpass filter are then demonstrated numerically and experimentally. As shown in Fig. 4(a), the simulated



(a) (b)

Figure 3: (a) Designed filter configuration with dimensional parameters in millimeter and (b) the fabricated sample.

and measured results are agreed with each other quite well, which demonstrate the validities for both results. There is a wide passband with measured 3-dB bandwidth of 0.65 GHz (from 3.0 GHz to 3.65 GHz) centered at 3.325 GHz. This result indicates a very small electric size of about 0.13λ, where λ is the center operating wavelength. The measured insert loss is about 1.4 dB and return loss is larger than 10 dB within the whole passband. And the peak transmission is -1.37 dB at 3.27 GHz, as shown in the inset of Fig. 4(a). There are also two transmission dips near below and upper the passband, so that this filter possesses well frequency selection properties. Moreover, further simulation shows that the suppression apart center frequency up to 8 GHz is larger than 20 dB and the first higher order passband is located near 10 GHz, as shown in Fig. 4(b). Therefore, this filter has a well out-of-band harmonic suppression characteristics.



(a) (b)

Figure 4: (a) Measured and simulated transmission and reflection properties of the miniaturized microscript bandpass filter, and (b) simulated transmission and reflection properties of the compact filter in a wide frequency range.

4. CONCLUSION

In this paper, a novel miniaturized microscript wideband bandpass filter is discussed by using the TSRRs configuration as resonator. Both numerical and experimental results demonstrate the proposed filter exhibits pretty well passband and out-of-band harmonic suppression characteristics. Such kind of filter configuration can be widely used for miniature radio frequency/microwave integrated circuits applications.

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