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Ultra-compact UHF Band-pass Filter Designed by Archimedes Spiral Capacitor and Shorted-loaded Stubs

Abstract: UHF microstrip band-pass filters (BPFs) that much smaller than the referred BPFs are proposed in this communication. For the designing purpose of compactness, archimedes spiral capacitor and ground-loaded stubs are utilized to enhance capacitances and inductance of a filter. Two compact BPFs denoted as BPF 1 and BPF 2 are designed by applying these techniques. The size of BPF 1 and BPF 2 are 0.062 $\lambda_g \times 0.056\ \lambda_g$ and 0.047 $\lambda_g \times$ 0.043 λ_g, respectively, where λ_g are guided wavelengths of the centre frequencies of the corresponding filters. The proposed filters were constructed and measured, and the measured results are in good agreement with the simulated ones.

Keywords: ultra-compact, UHF, band-pass filter, Archimedes spiral, shorted-loaded stubs

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1 Introduction

Planar band-pass filter (BPF) is widely researched due to its low cost, light weight, easy fabrication, and applications in RF front-end and wireless communication systems [1–6]. In recent years, compact system have become an urgent topic in modern microwave systems, therefore, minimizing size of planar BPF has gained extreme interesting [1–6]. Stepped-impedance resonators (SIR) were utilized in [1] and [2] for the purpose of compactness, and their filter sizes are 0.305 $\lambda_g \times 0.1\ \lambda_g$ and 0.15 $\lambda_g \times 0.16\ \lambda_g$, respectively. In [3] and [4], folded quarter-wavelength resonators are used for compact BPF design to achieve filter size of 0.13 $\lambda_g \times 0.18\ \lambda_g$ and 0.1 $\lambda_g \times 0.079\ \lambda_g$, respectively. The BPFs designed by stub-loaded resonators have compact size of 0.19 $\lambda_g \times 0.076\ \lambda_g$ (triple-mode) and 0.19 $\lambda_g \times 0.12\ \lambda_g$ (quad-mode) [5]. In our previous research [6], interdigital capacitor and shorted-loaded stubs are applied to achieve a small filter size of 0.15 $\lambda_g \times 0.13\ \lambda_g$.

It is found that these filters have similar size compare to their wavelength, though by different approaches. In other words, further size reduction is not easy. However, it is found in [6], size reduction mechanisms of the filter are the increased capacitance from interdigital capacitor and the inductance from shorted-loaded stubs. Therefore, further size reduction can be achieved by increasing the capacitance and inductance.

In this communication, for the purpose of further size reduction, shorted-loaded stubs to produce inductance are made in a form of elliptical ring to make better use of the area, and interdigital capacitor is replaced by archimedes spiral capacitor to get a larger capacity area, and then larger capacitance. Then, a BPF, denoted as BPF 1, is successfully designed to operate at UHF band with ultra-compact size. To further reduce the filter's size, an interdigital capacitor is conducted in the centre of BPF 1 to achieve a more compact filter denoted as BPF 2.

2 Design and results

The configuration of the proposed BPF 1 is shown in Figure 1. Fig. 1(a) is a top view and Fig. 1(b) is a 3D view. As shown in the figures, a two turn archimedes spiral with parameters $r_i = 3.5$ mm, $W_1 = 0.75$ mm and $W_2 = 0.5$ mm (the gap of the spiral is $(W_1 - W_2)/2$) is surrounded by an elliptical ring. Two gaps with width g are etched on the elliptical ring. The parameters of the elliptical ring are $r_1 = 9.3$ mm, $r_2 = 8.5$ mm, $W_0 = 0.8$ mm, $g = 1$ mm, $\theta = 45°$. Two vias with radius $r = 0.3$ mm are used to connect the elliptical ring and the ground plane. The archimedes spiral is connected to the elliptical ring with stubs $W_2 = 0.5$ mm and $W_3 = 0.25$ mm as shown in the figure. The width of the microstrip lines are fixed at $W_f = 1.55$ mm for

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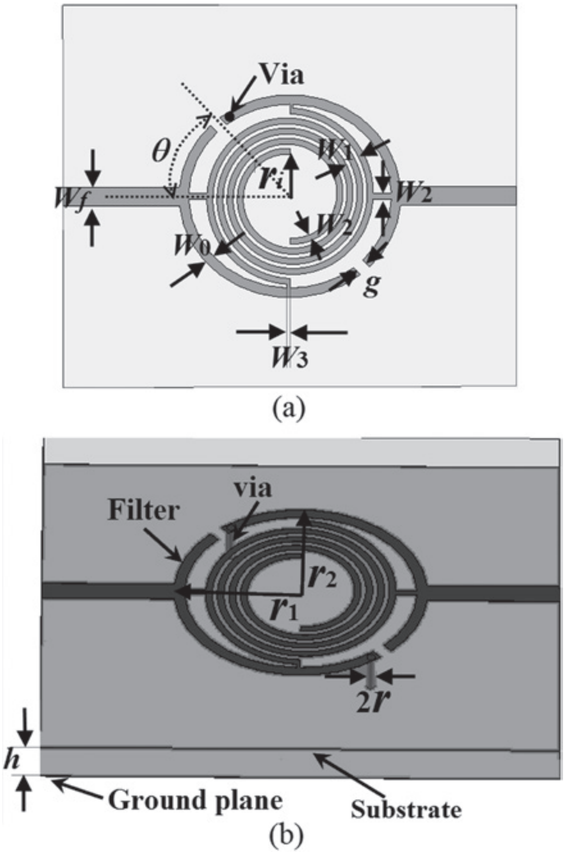

Fig. 1: Configuration of BPF 1: (a) top view, (b) 3D view.

50 Ω impedance. The filter is constructed on Rogers 5880 substrate with relative permittivity $\varepsilon_r = 2.2$ and height $h = 0.508$ mm. The size of the filter circuit is $2r_1 \times 2r_2 = 18.6$ mm × 17 mm.

The proposed BPF 1 is fabricated and measured as shown in Figure 2. Fig. 2(a) is a picture of the constructed filter. As shown in the figure, two SMA connectors are soldered at the ends of the microstrip lines for measurement with a vector network analyzer (VNA). In fact, the filter can be easily integrated to Integrated Circuit (IC) as it is fabricated by Printed Circuit Board (PCB) technique. The simulated and measured results of the filter are shown in Fig. 2(b). As shown in the figure, the simulated and measured results agree well with each other, and the filter operates at UHF band. It is found from the S_{21} curves, the simulated and measured 3 dB bandwidths are 160 MHz (0.76 GHz–0.92 GHz, 19.0% at 0.84 GHz) and 120 MHz (0.78 GHz–0.90 GHz, 14.3% at 0.84 GHz), respectively. It is shown that, the measured bandwidth is narrower than the simulated one, which is due to the loss of the filters that not considered in simulations. And the loss of the filter is owing to the loss of the substrate and the coarse welding of the SMA connectors. The attenuation of the stop-band is larger than 13 dB. Therefore, BPF 1 presents moderate good results with very small size, and it would be a good choice for very compact microwave systems.

The size of BPF 1 is very small. However, its size can be further reduced by utilizing interdigital capacitor in the centre to increase its capacitance. The filter is denoted as BPF 2 and demonstrated in Figure 3. As shown in Figure 3, a circular interdigital capacitor is placed in the centre of BPF 1. This design (BPF 2) makes good use of the area of BPF 1, and decreases the operating frequencies without increase filter size. Here, we only present the interdigital capacitor-related parameters as the other parameters can be referred from BPF 1. The parameters of the interdigital capacitor are $r_0 = 3$ mm, $e = 0.1$ mm, $s = 0.5$ mm, $L_1 = 5.5$ mm, $L_2 = 5$ mm, $L_3 = 4.5$ mm and $L_4 = 3.5$ mm.

The proposed BPF 2 is constructed and measured as shown in Figure 4. Fig. 4(a) and (b) demonstrate the picture and results of BPF 2, respectively. It is seen from the figure, the simulated and measured results agree well with each other. The simulated 3 dB bandwidth ranges from 0.59 GHz to 0.68 GHz (90 MHz, 14.1% at 0.64 GHz), and the measured 3 dB bandwidth ranges from 0.61 GHz

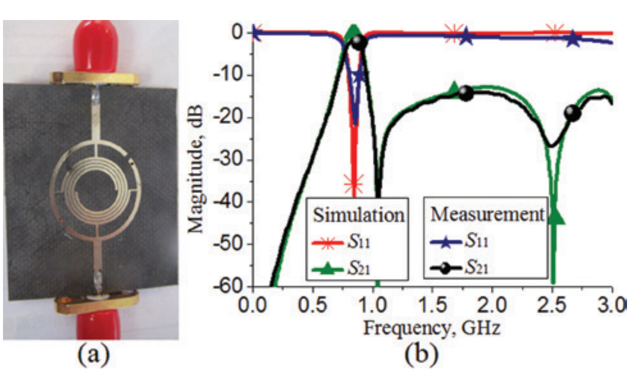

Fig. 2: BPF 1: (a) picture, (b) results.

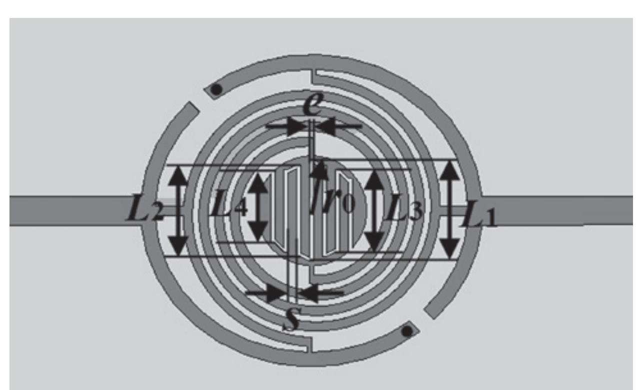

Fig. 3: Configuration of BPF 2.

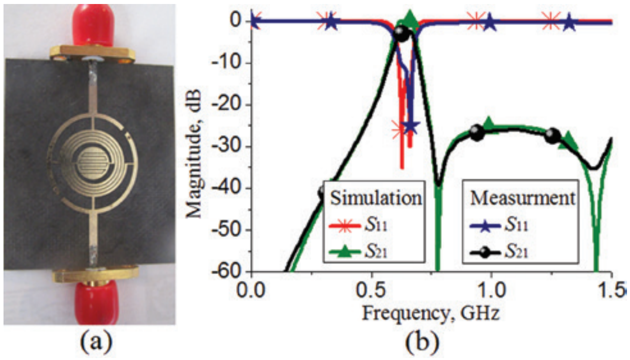

Fig. 4: BPF 2: (a) picture, (b) results.

to 0.67 GHz (60 MHz, 9.4% at 0.64 GHz). Similar to BPF 1, measured bandwidth of BPF 2 is also narrower than its simulated bandwidth. Thus, by utilizing a centre-located interdigital capacitor without increase filter's size, filters' centre frequencies decrease from BPF 1's 0.84 GHz to BPF 2's 0.64 GHz. The measured stop-band attenuation of BPF 2 is larger than 25 dB. It is notice that the stop-band attenuation of BPF 2 is 12 dB better than that of BPF 1. This is owing to the increased grounded-capacitance introduced by the centre-located interdigital patch to the ground.

3 Conclusion

Two BPFs based on archimedes spiral and ground-loaded stubs are designed. The sizes of the proposed filters are much smaller than the referred BPFs. For example, the size of BPF 1 and BPF 2 are only 17.8% and 10.4% of the filter of [6] (size referred to wavelength), respectively. The research also found that BPF 1 (14.3%, measured) presents larger bandwidth than BPF 2 (9.4%, measured), however, BPF 2 obtains better stop-band attenuation and size reduction. Therefore, both the proposed filters are very good choices for compact microwave systems, and we just need to weigh up which one is the best.

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