Novel Microstrip Ultra-Wideband Bandpass Filter Using Radial-Stub-Loaded Structure

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Abstract **─** A novel planar ultra-wideband (UWB) bandpass filter (BPF) using radial-stub-loaded resonator is proposed, where the resonator consists of three radial stubs, one located in the middle and two symmetrically at both sides. This radial-stub-loaded structure situates the first four resonant modes in the UWB passband (3.1~10.6 GHz) and makes the fifth resonant mode far away from this passband. To enhance the coupling degree, two interdigital coupled feed lines are utilized in this UWB filter. Finally, a UWB BPF with wide upper-stopband and sharp upper rejection skirt has been realized and its design steps have been also presented. The measured and full-wave simulated results of the proposed filter are in good agreement.

Index Terms **─** Bandpass filter, microstrip, radial-stub-loaded, ultra-wideband.

I. INTRODUCTION

UWB devices and systems have received great attention from both the academic and industrial fields since the U.S. Federal Communications Committee (FCC) fixed the UWB frequency spectrum range of 3.1 to 10.6 GHz for commercial use in 2002 [1]. As one of the key devices in a UWB system, UWB BPFs with low loss, compact size, and good selectivity attract the interest of the scholars and the industry. Many efforts have been carried out to make UWB BPFs better performance, e.g., the multiple-mode resonator (MMR) filters. A MMR with step-impedance structure was first presented to construct a UWB filter in [2]. However, this filter has a large size and its selectivity is also not very good. Then, three open-circuited stubs and three pairs of ones were employed to design MMR BPFs in [3] and [4], respectively, which produce four resonant modes in the passband. To improve the response and the rejection skirt of high frequency stopband, a novel UWB filter with three pairs of the rectangle stubs was introduced in [5]. Moreover, two types of quint-mode UWB filters were proposed to improve the in-band performance in [6] and [7]. The former one is using short-circuited shunt stub-embedded multiple-mode resonators, while the latter is based on dual stepped-impedance stub-loaded resonators without metalized via holes in the ground plane. In [8], the proposed multiple mode filter with a novel modified trisection stepped impedance resonator (SIR) is constructed to improve both in-band and out-band performance.

In this paper, a new UWB bandpass filter using triple-radial-stub loaded structure with interdigital coupling lines has been proposed. These triple radial stubs can not only situate the first four resonant modes in the passband but also move the fifth resonant mode up to the high frequency. To control the resonant modes of this structure within the FCC-regulated UWB passband, only a few variables need to be adjusted. Moreover, the proposed filter possesses an improved rejection skirt with a wider upper stopband compared with the References [2-8].

II. UWB BPF DESIGN

The structure of the proposed radial-stub-loaded UWB BPF on the printed circuit board (PCB) is shown in Fig. 1 (a). Figure 1 (b) is the equivalent network diagram of Fig. 1 (a). Three radial stubs are loaded in the middle of the resonator and the characteristic impedances of the filter input and output ports are both taken as 50 Ohm. The interdigital coupling lines can be seen as J-inverters, and their lengths are all around $\lambda g / 4$, where λg is the guided wavelength at the center frequency of the UWB filter.

The parameters l_2, w_1 and s_1 in Fig. 1 (a) can affect the coupling strength between the resonator and feed lines, while the variation of the resonant modes can be observed and analyzed easily in the case of weak coupling. The simulated S_{21}-Magnitude results of the proposed radial-stub-loaded UWB filter under weak (l_2 = 0.5 mm, w_1 = 0.1 mm, s_1 = 0.1 mm) and strong

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(l_2 = 7 mm, w_1 = 0.1 mm, s_1 = 0.1 mm) coupling are illustrated in Fig. 2 (a) and Fig. 2 (b), respectively, where Taconic RF-35 is used as the substrate of this filter with the relative dielectric constant of ε_r = 3.5 and thickness of 0.508 mm. As depicted in Fig. 2 (a), the in-band resonant modes of UWB (3.1-10.6 GHz) filter increase from two to four modes as the number of the radial stubs goes up; meanwhile, the harmonic responses are moved to higher frequency to make upper stopband wider. Furthermore, the rejection skirt of the filter is sharpened as the number of radial-stubs rises as shown in Fig. 2 (b). We can also see that the S_{21}-Magnitude curve in the UWB passband gradually rises towards the 0 dB line as the coupling strength increases. In the strong coupling case with l_2 = 7 mm, a desired UWB passband is realized. Compared with the filter using three rectangle stubs in [3], this structure using triple radial stubs achieves better performance.

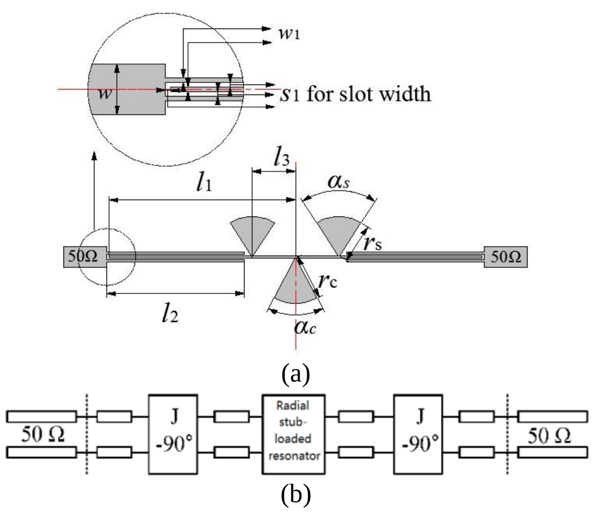
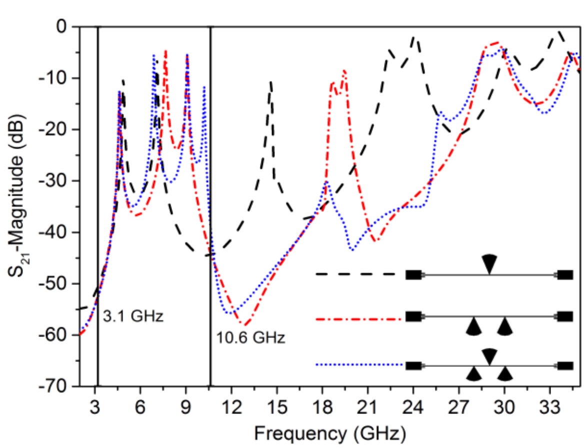


Fig. 1. (a) Schematic diagram of the proposed radial-stub-loaded UWB BPF (the structure is symmetrical with the red dash lines), and (b) its equivalent network diagram.



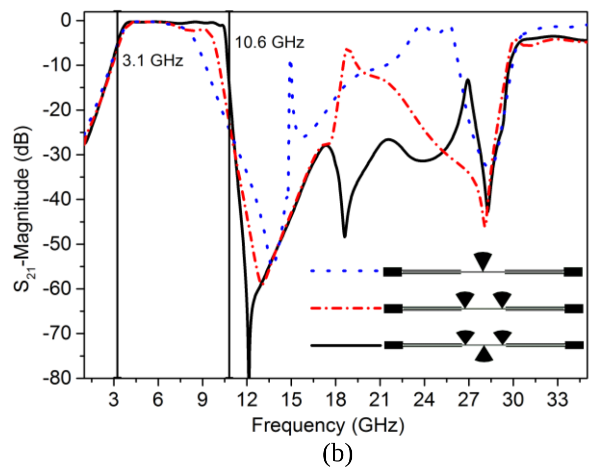
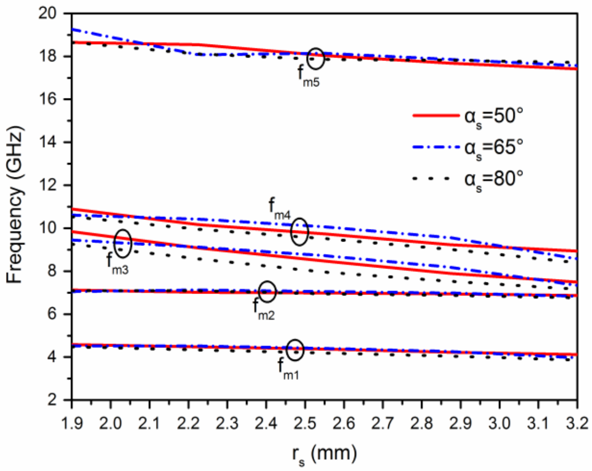


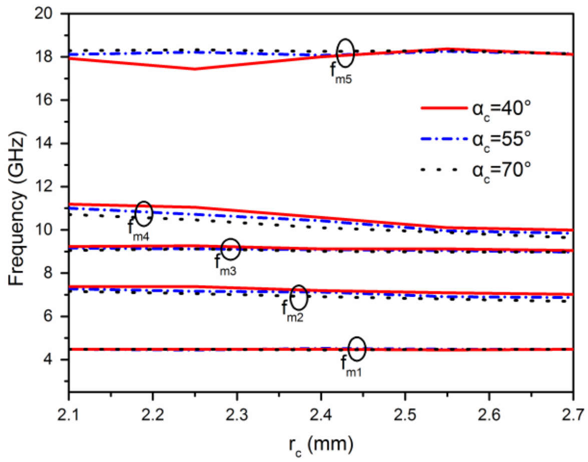
Fig. 2. Simulated S_{21}-magnitude comparisons of the filter: (a) when using single, dual and triple radial-stubs under weak coupling with l_2 = 0.5 mm, w_1 = 0.1 mm, s_1 = 0.1 mm, and (b) when using single, dual and triple radial-stubs under strong coupling with l_2 = 7 mm, w_1 = 0.1 mm, s_1 = 0.1 mm, where the other dimensions are fixed as l_1 = 9.5 mm, l_3 = 2.2 mm, w = 1.1 mm, r_c = 2.4 mm, r_s = 2.1 mm, $\alpha_c = 55^\circ$ and $\alpha_s = 65^\circ$.

Figure 3 illuminates the simulated frequency characteristics of the radial-stub-loaded resonator under weak coupling case of Fig. 1 (a) with varied r_s, α_s, and r_c, α_c respectively. We can see that the first four resonant frequencies, namely, f_{m1}, f_{m2}, f_{m3} and f_{m4} are located in the passband from 3.1 to 10.6 GHz, which can determine the passband frequency. Figure 3 (a) shows the relationship between parameters of two side radial stubs and the resonant frequencies. As r_s varied from 1.9 to 3.2 mm, f_{m3} and f_{m4} shift downwards but f_{m1} and f_{m2} almost remain unchanged although the angle of α_s changes from 50 to 80 degree, while f_{m5} stays around 18 GHz all the time. In Fig. 3 (b), f_{m1} and f_{m3} almost remain the same when r_c and α_c vary but f_{m4} decreases with the increase of r_c, while f_{m2} and f_{m4} increase with the decrease of α_c.

The aforementioned relationships assist us easily control the dimensions of the radial stub-loaded resonator to achieve the expected S_{21}-magnitude responses. Based on the above analysis, the design steps of the proposed filter are listed as follows. Firstly, we let l_2 equal to $\lambda g/4$. Secondly, l_3 will be chosen to meet the requirement of the lower cut-off frequency, and then make l_1 equal to around l_2+l_3. Thirdly, r_c, α_s, r_s, and α_c need to be adjusted to fit in the right side of the passband or the upper cut-off frequency. Finally, adjust w_1 and s_1 slightly to achieve the required coupling coefficient and meet the desired frequency selectivity.



(a)



(b)

Fig. 3. Simulated characteristics of the proposed radial-stub loaded structure under weak coupling case with varied: (a) α_s and r_s, (b) α_c and r_c, where the other dimensions are fixed as l_1 = 9.5 mm, l_2 = 0.5 mm, l_3 = 2.2 mm, s_1 = 0.1 mm, w = w_1 = 1.1 mm.

III. FABRICATION AND MEASUREMENTS

Based on the above analysis, a novel adjustable UWB BPF using radial-stub-loaded structure is designed and fabricated on a Taconic RF-35 substrate with a relative permittivity of 3.5 and a thickness of 0.508 mm. The variables shown in Fig. 1 are chosen as follows: l_1 = 9.5 mm, l_2 = 7 mm, l_3 = 2.2 mm, s_1 = 0.1 mm, w_1 = 0.1 mm, w = 1.1 mm, r_c = 2.4 mm, $\alpha_c = 55^\circ$, r_s = 2.1 mm, $\alpha_s = 65^\circ$. The overall size of the filter still only amounts to 19.2 mm × 4.5 mm, though a low dielectric constant of this substrate has been used. The photograph of the fabricated microstrip radial-stub-loaded UWB BPF is shown in Fig. 4.

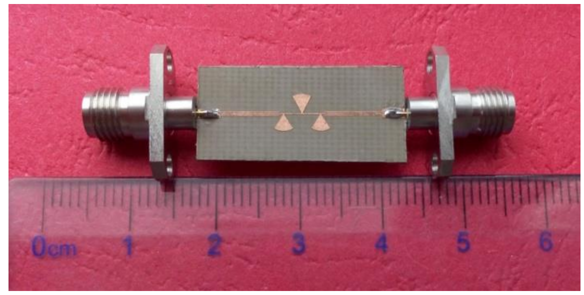
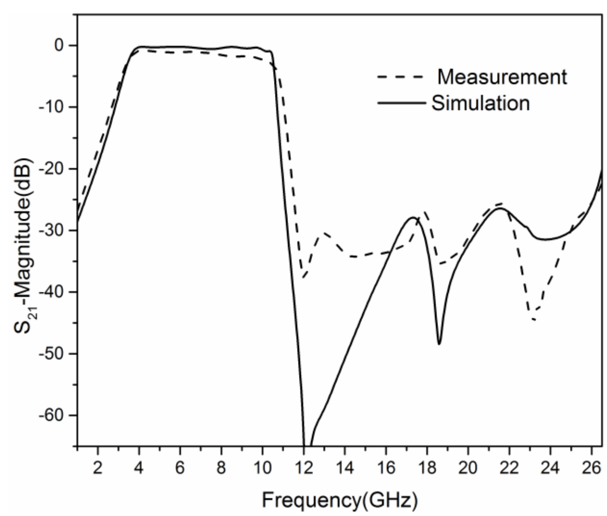
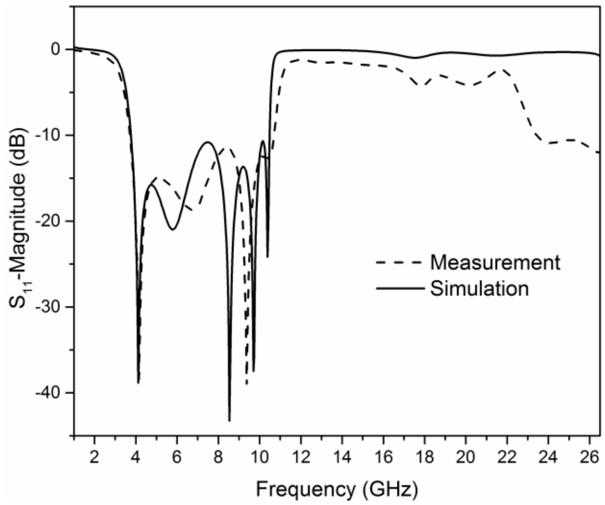


Fig. 4. Photograph of the fabricated microstrip UWB BPF.

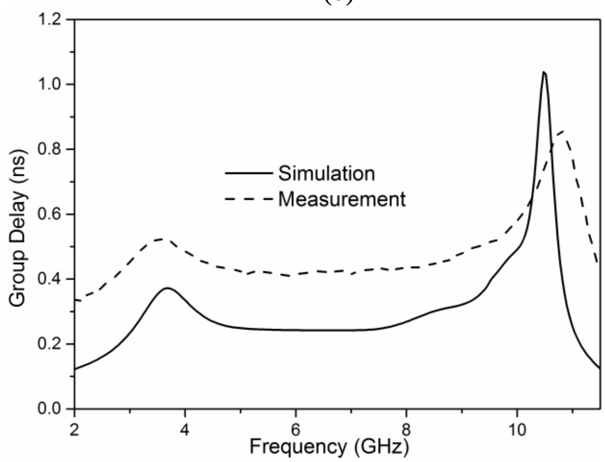
The simulated and measured results are accomplished by using software HFSS [9] and vector network analyzer, respectively. As the SMA connectors in Fig. 4 is rated to 26.5 GHz, the frequency range of measurement is set from 1 to 26.5 GHz. Figure 5 show S-parameter and group delay results of the proposed filter, where the simulations and measurements are in good agreement. Slight deviation is observed between simulated and measured results, which could be attributed to unexpected tolerances in fabrication, material parameters and soldering. In the measurement, the 3-dB bandwidth is from 3.4 to 10.5 GHz. As shown in Figs. 5 (a) and (b), the insertion loss, including the losses from two SMA connectors, is less than 1.8 dB while the return loss is greater than 11.5 dB from 3.4 GHz to 10.5 GHz, which achieves a fractional bandwidth of 102%. The upper out-of-band rejection is greater than 23 dB from 11 to 26.5 GHz, which realizes a significant improvement compared with the References [2-8]. Moreover, the measured group delay is less than 0.8 ns in the UWB passband as depicted in Fig. 5 (c).



(a)



(b)



(c)

Fig. 5. Simulated and measured results of: (a) S_{21}, (b) S_{11}, and (c) group delay of the proposed UWB BPF.

IV. CONCLUSION

In this paper, a UWB BPF based on radial-stub-loaded resonator has been presented. Following the design procedure, we successfully allocate the first four resonant modes of the proposed BPF within the FCC-regulated UWB passband. Compared with UWB BPFs in [2-8], the proposed structure has better skirt selectivity and out-of-band rejection demonstrated both in simulation and measurement. The measured results validate the proposed design.

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