Progress In Electromagnetics Research Letters, Vol. 14, 181–187, 2010

NOVEL UWB BPF USING QUINTUPLE-MODE STUB-LOADED RESONATOR

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Abstract—In this letter, a novel compact UWB bandpass filter (BPF) with sharp rejection skirt is realized using quintuple-mode stub-loaded resonator. The resonator can generate three odd-modes and two even-modes in the desired band. By simply adjusting the lengths of open stubs in shunt and short-circuited stubs, the first five resonant modes of the resonator can be roughly allocated within the 3.1–10.6 GHz UWB band meanwhile the sixth resonant mode in the upper-stopband can be suppressed. The pair of short stubs can generate two transmission zeros near the lower and upper cut-off frequencies, leading to a sharp rejection skirt. A quintuple-mode UWB BPF is designed and fabricated and the measured results demonstrate the feasibility of the design process.

1. INTRODUCTION

Many reports on ultra-wide band (UWB) bandpass filters (BPFs) are now available, because extensive studies on UWB devices and systems have been carried out after the Federal Communications Commission (FCC) approved the unlicensed frequency band 3.1–10.6 GHz for UWB applications [1–12]. Multiple-mode resonator (MMR) was proposed in [7] and it has been widely used as an important technique to design wideband or ultra wideband bandpass filters with improved performances and varied shapes [8–12]. In [7], an initial MMR with stepped-impedance configuration was originally reported to make use of its first three resonant modes to build up a BPF that covers the overall UWB bandpass, i.e., 3.1 to 10.6 GHz. Several other triple-mode

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UWB filters have been reported based on varied MMRs such as stub-loaded MMR [8], EBG-embedded MMR [9], one open stub and one short stub loaded MMR [10]. Recently, two quadruple-mode UWB filters with compact size are proposed. By introducing two short-circuited stubs with one quarter-wavelength to the modified triple-mode UWB filter, a quadruple-mode UWB bandpass filter with sharp out-of-band rejection is presented in [11]. Another quadruple-mode UWB BPF with improved upper-stopband performance is given using the new MMR formed by attaching three circular impedance-stepped stubs in shunt to a high impedance microstrip line [12].

In this letter, a novel quintuple-mode stub-loaded resonator is utilized to design a compact UWB BPF with sharp rejection skirt performance. The proposed resonator shown in Figure 1 is simple in structure, configured by attaching an impedance-stepped open stub at its central plane, short-circuited stubs in pairs and open stubs in pairs to the low impedance microstrip line of the conventional MMR [7]. The first five modes of the resonator can be roughly allocated within the 3.1–10.6 GHz UWB band while suppressing the sixth resonant mode in the upper-stopband. The pair of short-circuited stubs can generate two transmission zeros near the lower and upper cut-off frequencies, leading to a high rejection skirt. The UWB BPF is designed and fabricated, and measured results excellently agree with the simulated results.

2. QUINTUPLE-MODE STUB-LOADED RESONATOR

Figure 1 illustrates the schematics of the proposed UWB bandpass filter. It consists of two distinctive parts, i.e., quintuple-mode stub-loaded resonator and two interdigital coupled-lines. The interdigital coupled-lines can be equaled as two single transmission lines at the two sides and a J-inverter susceptance in the middle [12]. And the resonator is configured by attaching an impedance-stepped open stub

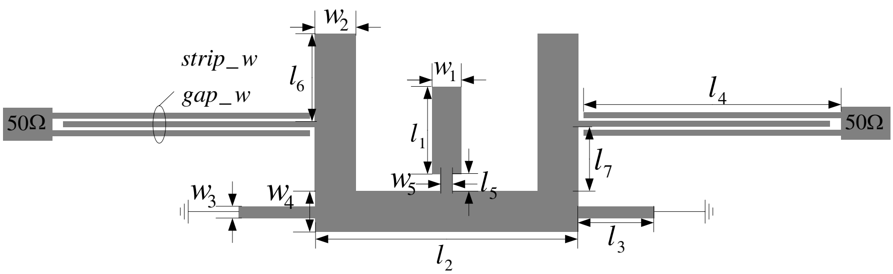
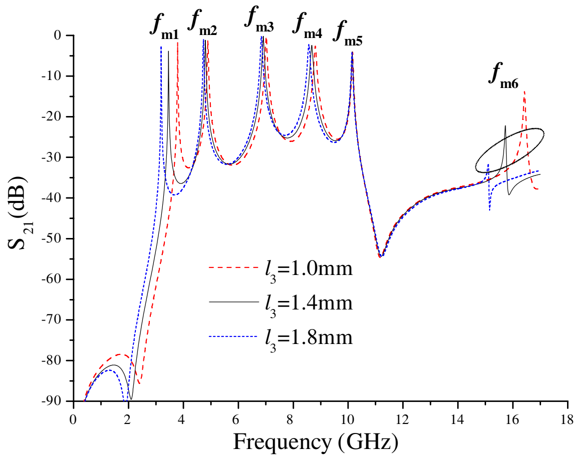


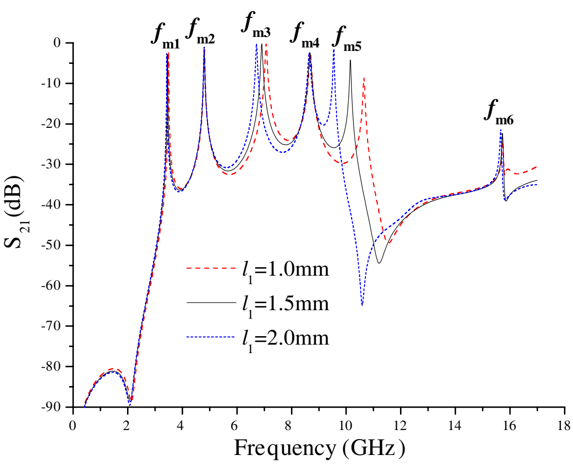
Figure 1. Schematic of the proposed UWB BPF.

(l_1, w_1, l_5, w_5) at its central plane, short-circuited stubs (l_3, w_3) in pairs and open stubs (l_6, w_2) in pairs to the low impedance microstrip line of the conventional MMR. Figure 2 shows S_{21} magnitude of the resonator circuit under the weak coupling case with $l_4 = 0.3\,\text{mm}$, fixed $strip\_w = 0.1\,\text{mm}$, $gap\_w = 0.05\,\text{mm}$ in order to investigate its resonant behaviour.

Figure 2(a) interprets the simulated S_{21}-magnitude of the quintuple-mode stub-loaded resonator circuit with varied l_3. The short stubs in pairs is applied to push the first resonant mode (f_{m1}) into the desired passband while sharpening the rejecting skirt of the passband [11]. So it can be seen that there are six main resonant



(a)



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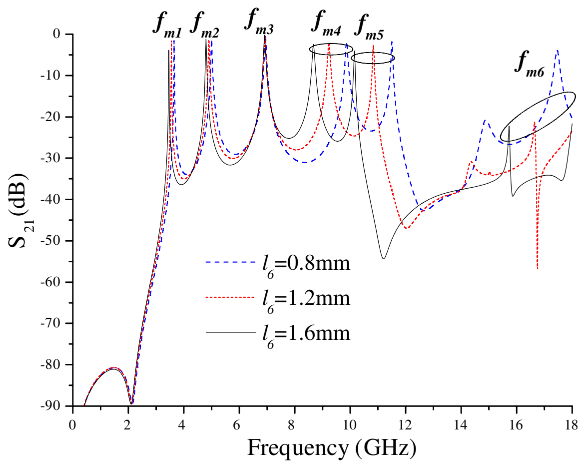


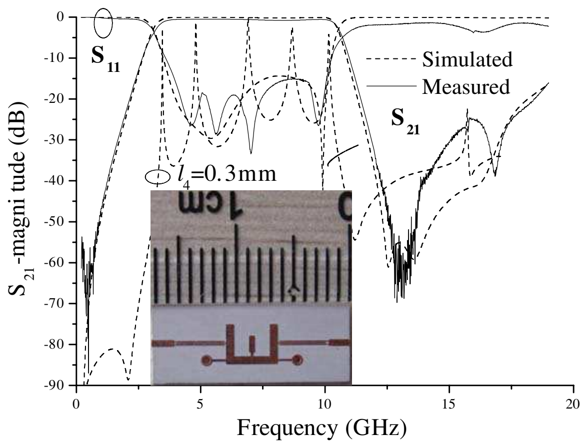
(c)

Figure 2. Simulated S_{21}-magnitude of weak coupling quintuple-mode resonator with $l_2 = 4.5\,\mathrm{mm}$, $l_4 = 4.4\,\mathrm{mm}$, $l_5 = 0.3\,\mathrm{mm}$, $l_7 = 1.1\,\mathrm{mm}$, $w_1 = 0.5\,\mathrm{mm}$, $w_2 = w_4 = 0.7\,\mathrm{mm}$, $w_3 = w_5 = 0.2\,\mathrm{mm}$, *strip_w* $= 0.1\,\mathrm{mm}$, *gap_w* $= 0.05\,\mathrm{mm}$ (a) with fixed $l_1 = 1.5\,\mathrm{mm}$, $l_6 = 1.6\,\mathrm{mm}$ and varied l_3 (b) with fixed $l_3 = 1.4\,\mathrm{mm}$, $l_6 = 1.6\,\mathrm{mm}$ and varied l_1 (c) with fixed $l_1 = 1.5\,\mathrm{mm}$, $l_3 = 1.4\,\mathrm{mm}$ and varied l_6.

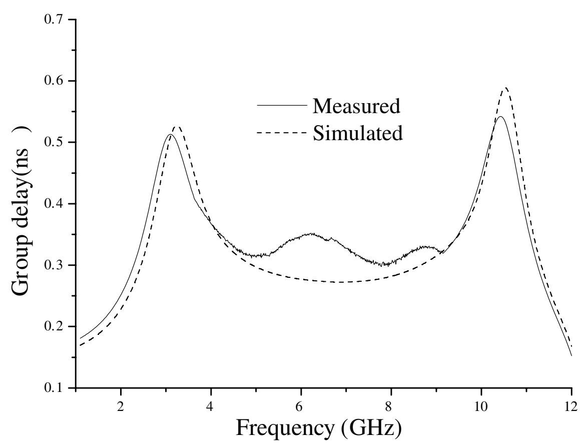
modes, i.e., four odd-modes (f_{m1}, f_{m2}, f_{m4}, f_{m6}) and two even-modes (f_{m3}, f_{m5}), in the range of 0.1–17 GHz. The odd-mode f_{m6} suppressed below 10 dB and four resonate modes in the desired band move towards the lower frequency except the even-mode f_{m5} are basically fixed, while changing the length l_3 from 1.0 mm to 1.8 mm.

As length l_1 of impedance-stepped open stub varying from 1.0 mm to 2.0 mm shown in the Figure 2(b), two even-modes tend to shift downwards, whereas four odd-modes keep almost unchanged. It is well valid in theory that the central location of the resonator corresponds to a short circuit or perfect electrical wall for odd modes, whose characteristics are hardly affected by the loaded impedance-stepped open stub, whereas it indicates an open circuit or perfect magnetic wall for all the even resonant modes [12]. In addition, as shown in Figure 2(c), all the resonant modes except the even-mode f_{m3} move towards the lower frequency while changing the length l_6 from 0.8 to 1.6 mm in the range of 0.1–18 GHz. Thus, the length (l_6) of the two side open stubs can provide an additional degree of freedom to adjust the locations of the first five resonant frequencies in an alternative way. Besides, a transmission zero excited by the open stubs in pairs can diminish the sixth resonant mode (f_{m6}) [11].

It can be found from the Figure 2 that the second resonant mode f_{m2} remains almost unchanged or change a little, as varying the lengths l_1, l_3 and l_6. Thus, the resonance frequency f_{m2} is approximatively determined by the conventional MMR [7] and can be allocated in a quarter of the passband and the other four resonance frequencies can be adjusted within the desired passband by simply varying the parameters l_1, l_3 and l_6.



(a)



(b)

Figure 3. Simulated and measured frequency responses of the UWB BPF: (a) S-magnitudes. (b) Group delay.

3. QUINTUPLE-MODE UWB FILTER

The two interdigital coupled lines are also used to provide sufficiently strong coupling degree and the UWB band is formed while the in-band resonant peaks remain nearly unchanged [9–12]. Based on the aforementioned quintuple-mode stubloaded resonator, the five resonant modes ($f_{m1}, f_{m2}, f_{m3}, f_{m4}, f_{m5}$) can be used to make up of a compact UWB BPF, if this quintuple-mode stub-loaded resonator is properly fed with interdigital coupled lines with increased the length $l_4 = 4.4\,\text{mm}$ [7] and fixed $strip\_w = 0.1\,\text{mm}$, $gap\_w = 0.05\,\text{mm}$. The frequency response of the filter is simulated and shown in Figure 3(a). It is interpreted that the simulated five resonance frequencies under the weak coupling case ($l_4 = 0.3\,\text{mm}$) are adjusted within the 3.1–10.6 GHz UWB band. The substrate used here has a relative dielectric constant of 10.5 and a thickness of 0.635 mm. The filter is simulated by HFSS and the optimized parameters are: $l_1 = 1.5\,\text{mm}$, $l_2 = 4.5\,\text{mm}$, $l_3 = 1.4\,\text{mm}$, $l_5 = 0.3\,\text{mm}$, $l_6 = 1.6\,\text{mm}$, $l_7 = 1.1\,\text{mm}$, $w_1 = 0.5\,\text{mm}$, $w_2 = w_4 = 0.7\,\text{mm}$, $w_3 = w_5 = 0.2\,\text{mm}$, respectively.

After studying the characteristic of the filter, a compact UWB BPF with sharp rejection skirt is fabricated on the RT6010 substrate through the standard PCB fabrication process. The measured frequency responses of the S-magnitude are shown in Figure 3(a) and illustrated good agreement with simulated results. The measured 2 dB passband is within the desired UWB passband (e.g., 3.1–10.6 GHz) and its measured return loss is less than −13 dB. The upper-stopband in experiment is greatly extended up to 18.3 GHz with an insertion loss better than 20 dB. The measured in-band group delay in Figure 3(b) is varying from 0.3 to 0.5 ns, showing a good linearity.

4. CONCLUSIONS

A novel compact UWB BPF with good in-band and sharp rejection skirt performances is proposed with the quintuple-mode stubloaded resonator in this letter. By simply adjusting dimensions of the stubs, the first five resonant modes of the resonator can be roughly allocated in the desired UWB passband while suppressing the sixth resonant mode in the upper-stopband. The short stubs in pairs can generate two transmission zeros near the lower and upper cut-off frequencies, leading to a high rejection skirt. The simulated results are finally verified by the experiment of the fabricated filter.

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