Progress In Electromagnetics Research Letters, Vol. 14, 111–117, 2010

COMPACT QUINTUPLE-MODE UWB BANDPASS FILTER WITH GOOD OUT-OF-BAND REJECTION

H.-W. Deng, Y.-J. Zhao, X.-S. Zhang, L. Zhang and S.-P. Gao

College of Information Science and Technology
Nanjing University of Aeronautics and Astronautics
Nanjing 210016, China

Abstract—In this paper, a novel compact quintuple-mode UWB bandpass filter (BPF) with sharp rejection skirt and wide upper-stopband performances is realized using stub-loaded multiple-mode resonator (MMR). The proposed resonator is formed by attaching two pairs of circular impedance-stepped open stubs in shunt and a pair of short-circuited stubs to high impedance microstrip line. By simply adjusting the radius of circular impedance-stepped open stubs and the lengths of 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 high resonant modes in the upper-stopband can be suppressed. The short stubs in pairs can generate two transmission zeros near the lower and upper cut-off frequencies, leading to sharper rejection skirt outside the desired passband. Finally, a quintuple-mode UWB BPF is designed and fabricated, and the measured results demonstrate the feasibility of the design process.

1. INTRODUCTION

Since the Federal Communications Commission (FCC) in the USA released the unlicensed frequency range from 3.1 to 10.6 GHz for commercial communication application in 2002 [1], tremendous interest has been arising in the exploration of a variety of UWB BPFs [1–12]. The technique based on the MMR has been increasingly applied to design a class of UWB BPFs [7–12]. In [7], an initial MMR with stepped-impedance configuration was originally reported to make use of its first three resonant modes in building up a BPF that covers the overall UWB passband. In [8], three triple-mode resonators

Corresponding author: H.-W. Deng (ceceliayan1008@yahoo.com.cn).

are cascaded and properly coupled together to make a ninth-order wideband filter with enhanced out-of-band rejection and extended upper-stopband at the cost of enlarged overall size. In [9], capacitive-ended interdigital coupled lines are constructed to allocate coupling zeros at the fourth resonant mode of the initial MMR, thus certainly widening the upper-stopband of the resultant triple-mode UWB filter. In [10], an EBG-embedded triple-mode resonator (TMR) constitutes to highly extend the upper-stopband with the help of its high-band attenuation. Recently, two quadruple-mode UWB filters with compact size are proposed. By introducing two short-circuited stubs with one quarter-wavelength to modified triple-mode UWB filter, a quadruple-mode UWB BPF with sharp out-of-band rejection is presented in [11]. Another quadruple-mode UWB BPF with improved upper-stopband performance is given by using the new MMR which is formed by attaching three pairs of ring open stubs in shunt to a high impedance microstrip line [12].

In this paper, a novel stub-loaded MMR is utilized to design a compact quintuple-mode UWB BPF with sharp rejection skirt and wide upper-stopband performances. The resonator is simple in structure, shown in Figure 1, configured by attaching two pairs of circular impedance-stepped open stubs in shunt and a pair of short-circuited stubs to high impedance microstrip line. The first five modes of the resonator can be roughly allocated within the 3.1–10.6 GHz UWB band while suppressing the high resonant modes in the upper-stopband. The short stubs in pairs can generate two transmission zeros near the lower and upper cut-off frequencies, leading to higher rejection skirt outside the desired passband [11]. The UWB BPF is designed and fabricated, and the measured results excellently agree with the simulated ones.

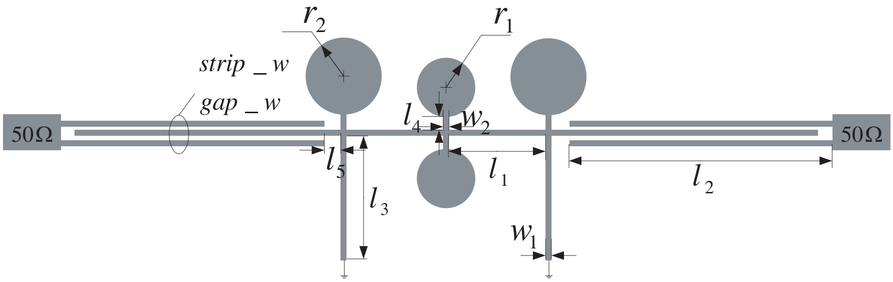

Figure 1. Schematic of quintuple-mode UWB BPF.

2. QUINTUPLE-MODE UWB FILTER

The schematic of the quintuple-mode UWB BPF is shown in Figure 1. The interdigital coupled lines can be equal to two single transmission lines at the two sides and a J-inverter susceptance in the middle [10]. The proposed MMR is configured by attaching two pairs of circular impedance-stepped open stubs in shunt and a pair of short-circuited stubs to high impedance microstrip line.

The MMR is coupled to $50\,\Omega$ input/output feeding lines under the weak coupling case with $l_2 = 0.3$ mm and fixed strip_w = 0.1 mm, gap_w = 0.05 mm in order to investigate its resonant behaviour [8]. Figure 2(a) interprets the simulated S_{21}-magnitude of the stub-loaded MMR circuit with varied r_1. It can be seen that there are seven main resonant modes, i.e., three odd-modes (f_{m1}, f_{m2}, f_{m4}), two even-modes (f_{m3}, f_{m5}) and two mixing modes (f_{m6}, f_{m7}) simultaneously excited by odd- and even-mode resonators, in the range of 0.1–27 GHz. As radius r_1 varying from 0.45 mm to 0.65 mm, two even-modes tend to shift downwards, whereas two mixing modes are suppressed below 10 dB, and three 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 circular impedance-stepped open stubs (r_1), whereas it indicates an open circuit or perfect magnetic wall for all the even resonant modes [12].

The short stubs in pairs are applied to push the first resonant mode (f_{m1}) into the desired passband while sharpening the rejecting skirt of the passband [11]. For the even-modes, the existence of the short stubs has relatively small effect. As depicted in Figure 2(b), the mixing mode f_{m7} is suppressed below 10 dB, and three odd-modes move towards the lower frequency, whereas the even-modes and mixing mode f_{m6} are basically fixed, while changing the length l_3 from 1.4 mm to 2.2 mm. In addition, as shown in Figure 2(c), the three resonant modes (f_{m4}, f_{m5}, f_{m6}) move towards the lower frequency while other modes remain almost unchanged, while changing the radius r_2 from 0.45 mm to 0.65 mm. Thus, the two side circular impedance-stepped open stubs with varied r_2 can provide an additional degree of freedom to adjust the locations of the resonant modes (f_{m4}, f_{m5}). Besides, they excite transmission zero to diminish the resonant mode (f_{m6}) [11]. Consequently, the second resonance frequency can be allocated in a quarter of the passband, and the other four resonance frequencies can be adjusted within the desired passband.

Based on the above stub-loaded MMR, the first five resonant modes ($f_{m1}, f_{m2}, f_{m3}, f_{m4}, f_{m5}$) can be used to make up of a compact

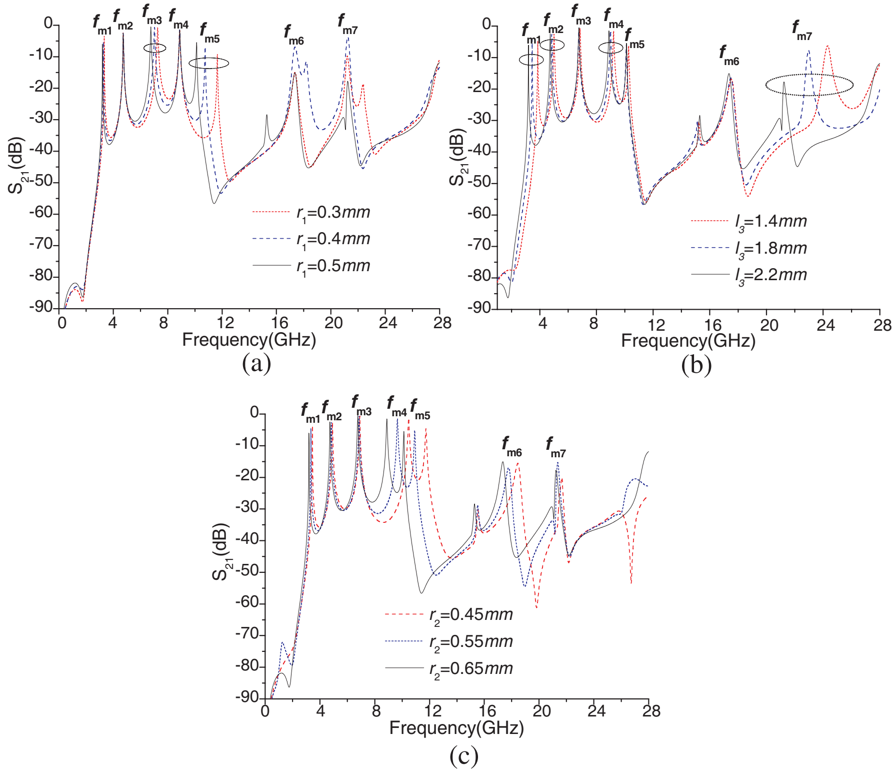

Figure 2. Simulated S_{21}-magnitude of weak coupling stub-loaded MMR with $l_1 = 1.65$ mm, $l_2 = 4.5$ mm, $l_4 = 0.2$ mm, $l_5 = 0.2$ mm, $w_1 = w_2 = 0.1$ mm, strip_w = 0.1 mm, gap_w = 0.05 mm. (a) With fixed $l_3 = 2.2$ mm, $r_2 = 0.65$ mm and varied r_1. (b) With fixed $l_3 = 2.2$ mm, $r_2 = 0.65$ mm and varied l_3. (c) With fixed $l_3 = 2.2$ mm, $r_2 = 0.65$ mm and varied r_2.

quintuple-mode UWB BPF, if this MMR is properly fed with interdigital coupled lines with increased length $l_2 = 4.5$ mm and fixed strip_w = 0.1 mm, gap_w = 0.05 mm. At the same time, a transmission zero excited by the two interdigital coupled lines can be used to suppress resonant mode (f_{m7}) and realize wide upper-stopband [9]. The frequency response of the filter with sharp rejection skirt and wide upper-stopband is simulated and shown in Figure 3(a). 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: $l_1 = 1.65$ mm, $l_2 = 4.5$ mm, $l_3 = 2.2$ mm, $l_4 = 0.2$ mm, $l_5 = 0.2$ mm, $w_1 = w_2 = 0.1$ mm, $r_1 = 0.5$ mm, $r_2 = 0.65$ mm, strip_w = 0.1 mm, gap_w = 0.05 mm, respectively.

3. SIMULATED AND MEASURED RESULTS

After analyzing the characteristic of the filter, a compact quintuple-mode UWB BPF is fabricated on the RT6010 substrate through the standard PCB fabrication process. Figure 3(b) depicts the photograph of the fabricated filter. The measured frequency responses of the S-magnitude are shown in Figure 3(a) and demonstrate good agreement with each other. The measured 1.5 dB passband is within the desired UWB passband (e.g., 3.1–10.6 GHz), and its measured return loss is less than −14.9 dB. The 3 dB passband covers the range of 2.96–10.8 GHz, and it has a fractional bandwidth of 114%. The upper-stopband in experiment is greatly extended up to 27 GHz with an insertion loss larger than 22 dB. In addition, the measured in-band group delay in Figure 3(b) is varying from 0.32 to 0.55 ns, indicating a good linearity.

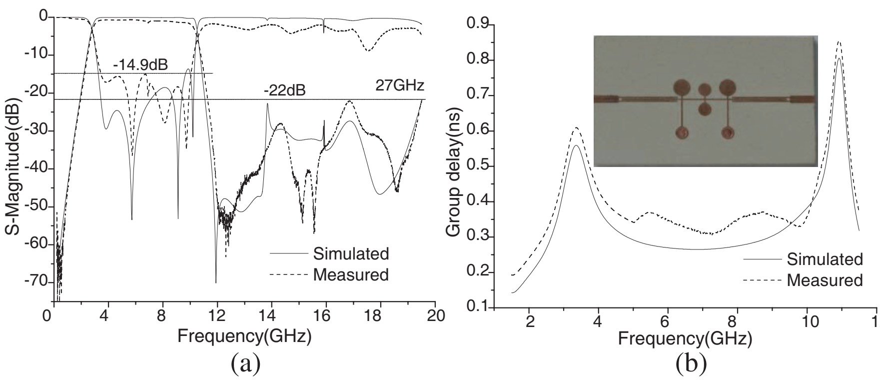

Figure 3. Simulated and measured frequency responses of the quintuple-mode UWB filter. (a) S-magnitudes. (b) Group delay.

4. CONCLUSIONS

In this work, a novel compact quintuple-mode UWB BPF with good in- and out-band rejection performances is proposed using the stub-loaded MMR formed by attaching two pairs of circular impedance-stepped open stubs in shunt and a pair of short-circuited stubs to high impedance microstrip line. By simply adjusting dimensions of the stubs, the first five resonant modes of the resonator can be roughly allocated to the desired UWB passband meanwhile the high resonant modes 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 sharper rejection skirt outside the desired passband. The simulated results are finally verified by the experiment of the fabricated filter.

ACKNOWLEDGMENT

This work was supported in part by the China South-East University State Key Laboratory of Millimeter Waves.

REFERENCES

1. Ishida, H. and K. Araki, "Design and analysis of UWB bandpass filter," *Proc. IEEE Topical Conf. Wireless Comm. Tech.*, 457–458, Oct. 2003.
2. Hsu, C. L., F.-C. Hsu, and J. T. Kuo, "Microstrip bandpass filters for ultra-wideband (UWB) wireless communications," *IEEE MTT-S Int. Dig.*, 679–682, Jun. 2005.
3. Chen, H. and Y.-X. Zhang, "A novel and compact UWB bandpass filter using microstrip fork-form resonators," *Progress In Electromagnetics Research*, PIER 77, 273–280, 2007.
4. Naghshvarian-Jahromi, M. and M. Tayarani, "miniature planar UWB bandpass filters with circular slots in ground," *Progress In Electromagnetics Research Letters*, Vol. 3, 83–97, 2008.
5. An, J., G.-M. Wang, W.-D. Zeng, and L.-X. Ma, "UWB filter using defected ground structure of von koch fractal shape slot," *Progress In Electromagnetics Research Letters*, Vol. 6, 61–66, 2009.
6. Hsiao, P.-Y. and R.-M. Weng, "compact open-loop UWB filter with notched band," *Progress In Electromagnetics Research Letters*, Vol. 7, 149–159, 2009.
7. Zhu, L., S. Sun, and W. Menzel, "Ultra-wideband (UWB) bandpass filters using multiple-mode resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 11, 796–798, Nov. 2005.
8. Sun, S. and L. Zhu, "Capacitive-ended interdigital coupled lines for UWB bandpass filterswith improved out-of-band performances," *IEEE Microw. Wireless Compon. Lett.*, Vol. 16, No. 8, 440–442, Aug. 2006.
9. Chiou, Y.-C., J.-T. Kuo, and E. Cheng, "Broadband quasi-Chebyshev bandpass filters with multimode stepped-impedance resonators (SIRs)," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 8, 3352–3358, Aug. 2006.
10. Wong, S. W. and L. Zhu, "EBG-embedded multiple-mode

resonator for UWB bandpass filter with improved upper-stopband performance," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, No. 6, 421–423, Jun. 2007.

11. Wong, S. W. and L. Zhu, "Quadruple-mode UWB bandpass filter with improved out-of-band rejection," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, No. 3, 152–154, Mar. 2009.
12. Yao, B. Y., Y. G. Zhou, Q. S. Cao, and Y. C. Chen, "Compact UWB bandpass filter with improved upper-stopband performance," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, No. 1, 27–29, Jan. 2009.