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A Novel Compact Microstrip UWB Bandpass Filter with Improved Out-of-Band Rejection

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Abstract—A new compact microstrip ultra-wideband (UWB) bandpass filter (BPF) with improved out-of-band rejection and good selectivity is proposed using a modified ring multiple-mode resonator (MMR). The initial UWB bandpass filter comprises interdigital coupled lines and a conventional ring MMR. Then, four high-low impedance resonant cells are periodically placed in the inner area of the conventional ring MMR, which have the properties of achieving harmonic suppression and size reduction. To validate the design theory, a new compact microstrip UWB BPF with improved out-of-band rejection is designed and fabricated. Both simulated and experimental results are provided with good agreement.

1. INTRODUCTION

Ultra-wideband (UWB) radio technology has been getting more and more popularity for high-speed wireless connectivity, since the Federal Communications Commission (FCC)'s decision to permit the unlicensed operation band from 3.1 GHz to 10.6 GHz in February 2002 [1]. There are several advantages for UWB radio system, such as transmitting higher data rates, requiring lower transmit power and simplifying the error control coding. UWB bandpass filter (BPF), as one of the essential components of the UWB systems, has gained great attention in recent years. There are many techniques presented to design UWB bandpass filters [2–6]. In [2], high-pass/low-pass filters are directly cascaded to construct a UWB BPF, but the insertion loss and overall circuit size are inevitably increased. In [3, 4], a multilayer broadside-coupled structure is used to obtain UWB performance, but the multi-layer structure is hardly compatible with the existing microwave-integrated circuit. In [5], a multiple-mode resonator (MMR) is utilized to realize a UWB BPF, but the proposed filter has a narrow upper stop-band. In [6], a three-line coupled resonator is employed to achieve a UWB BPF, but the filter selectivity is not ideal.

In this letter, a new compact ultra-wideband (UWB) bandpass filter (BPF) with improved out-of-band rejection and good selectivity is proposed and designed. The initial UWB BPF comprises interdigital coupled lines and a conventional ring multiple-mode resonator (MMR). Then, four high-low impedance resonant cells are periodically placed in the inner area of the conventional ring MMR, which have the features of achieving harmonic suppression and size reduction while maintaining the characteristics of a conventional ring UWB BPF. Finally, both simulation and measurement results are provided to verify the design method.

2. DESIGN OF UWB BPF WITH HARMONIC SUPPRESSION

The schematic layout of the proposed UWB bandpass filter is shown in Fig. 1. The initial UWB bandpass filter is constructed by interdigital coupled lines and a conventional ring multiple-mode resonator (MMR) as shown in Fig. 1(a). Four high-low impedance resonant cells placed inside the

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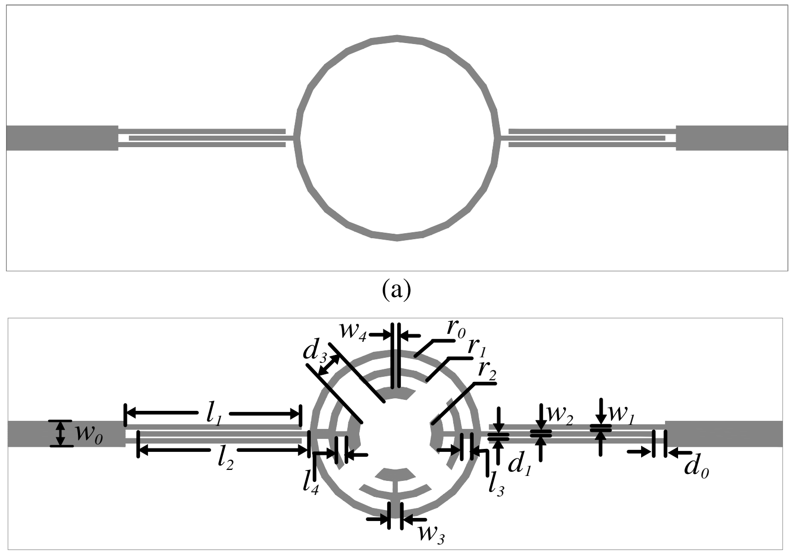

(a)

(b)

Figure 1. Layout of the proposed UWB BPF with ring MMR. (a) Layout of the UWB BPF with conventional ring MMR. (b) Layout of the UWB BPF with modified ring MMR.

free area of the conventional ring MMR is shown in Fig. 1(b). Each unit cell comprises two high-impedance lines and two low-impedance lines which are cascaded alternately. The high-impedance lines are only loaded at the sites connected to the ring, which causes inductances and in a lumped form, so that we ignore its influence on the per unit length inductance of the main transmission lines. The low-impedance lines are loaded parallel to the main transmission lines, which causes/leads to capacitances and in a distributed form. This will increase the per unit length capacitance of the main transmission lines. Thus, this type of slow-wave loading will mainly increase shunt capacitance in the UWB bandpass filter. The effective characteristic impedance Z and propagation constant β are given by:

$$Z = \sqrt{\frac{L_0}{C_0 + C_1}} \tag{1}$$

$$\beta = \sqrt{L_0 \left(C_0 + C_1\right)} \tag{2}$$

where L_0 and C_0 are the distributed inductance and capacitance without loading per unit length, respectively, and C_1 is the effective distributed capacitance caused by the periodic loading per unit length. Clearly, the propagation constant is increased by the periodic capacitive loading. An increased propagation constant means that a shorter physical structure can be used to yield a required electrical length relative to a conventional transmission line. This new type of slow-wave loading occupies no extra area of the circuit as the periodic slow-wave loading is placed at the free area inside the preceding UWB bandpass filter. We can get a desired slow-wave factor by properly adjusting the novel UWB bandpass filter's structure parameters. Therefore, a compact UWB bandpass filter with improved out-of-band rejection and good selectivity can be achieved based on the high slow-wave factor.

3. EXPERIMENTAL RESULTS

The UWB BPF has been designed on a substrate RT /Duroid 4003 with a dielectric constant of 3.38, thickness of 0.508 mm, and loss tangent of 0.0027. The structural parameters for the UWB filter circuit are (as illustrated in Fig. 1(b)): $l_1 = 7.5\,\text{mm}$, $l_2 = 7.4\,\text{mm}$, $l_3 = 0.5\,\text{mm}$, $l_4 = 0.5\,\text{mm}$, $w_0 = 1.1\,\text{mm}$, $w_1 = 0.2\,\text{mm}$, $w_2 = 0.2\,\text{mm}$, $w_3 = 0.4\,\text{mm}$, $w_4 = 0.2\,\text{mm}$, $d_0 = 0.5\,\text{mm}$, $d_1 = 0.1\,\text{mm}$, $r_0 = 3.6\,\text{mm}$, $r_1 = 2.8\,\text{mm}$, $r_2 = 2.1\,\text{mm}$. Fig. 2 shows the simulated parameters of the proposed UWB bandpass filter. As can be seen, the out-of-band rejection and selectivity of the UWB bandpass filter is greatly improved using the modified ring MMR. In fact, the modified ring MMR can also effectively reduce the occupied area to 76% of the conventional ring MMR.

Finally, the fabricated UWB BPF is measured with an Agilent N5244A vector network analyzer. Simulated and measured scattering parameters described in Fig. 3 have good agreement. Referring to Fig. 3, the fabricated UWB BPF has a passband from 3.1 GHz to 10.6 GHz and 110% fractional bandwidth (FBW) at 6.85 GHz. The mid-band insertion loss is 0.37 dB, and the return loss is higher than 10 dB within the whole passband. The upper stopband is really stretched up to 30 GHz, over which an insertion loss or attenuation is higher than 10 dB. The deviations of the measurements from the simulations are attributed to fabrication tolerance as well as SMA connectors. Comparisons with other

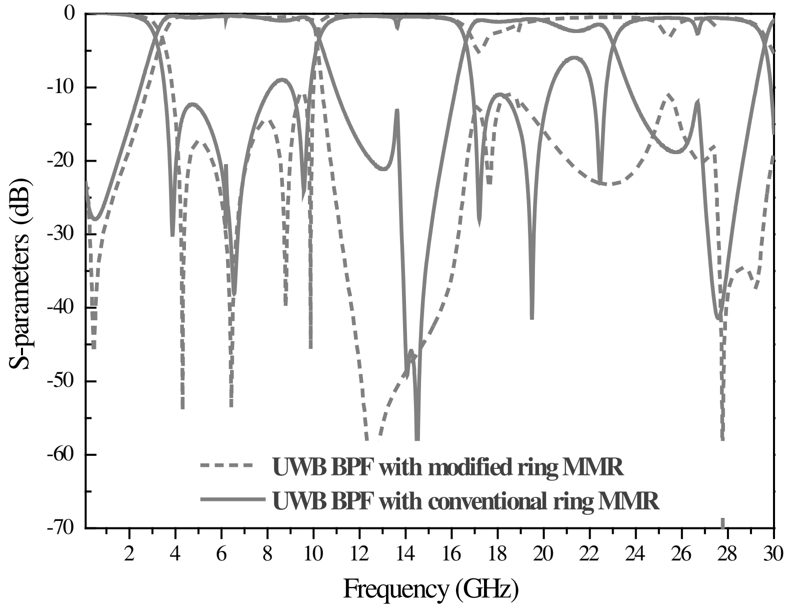

Figure 2. Simulated S-parameters of the proposed UWB BPF with ring MMR.

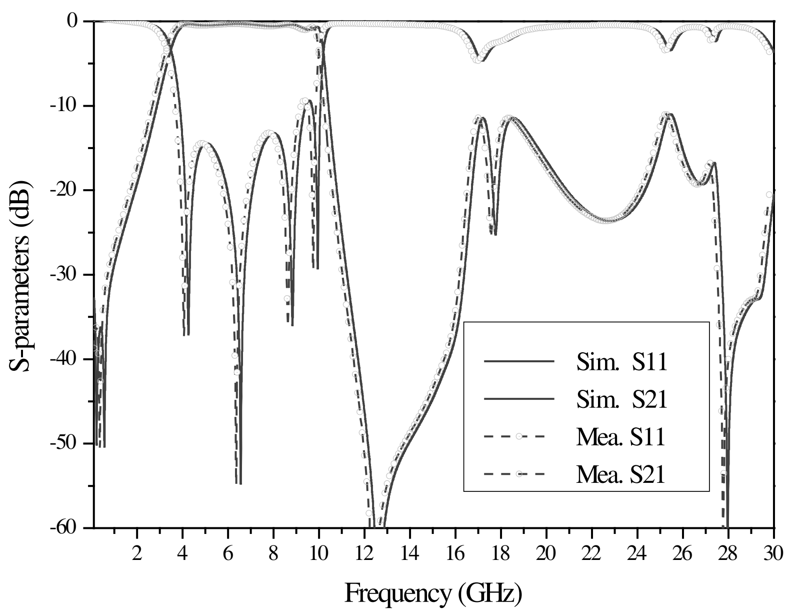

Figure 3. Measured and Simulated S-parameters of the proposed UWB BPF.

Table 1. Comparisons with other reported UWB bandpass filters.

Ref.	Circuit dimension	3 dB FBW	Roll-off Rate (dB/GHz)	Stop-band (GHz)
[3]	3-D	86%	23	18
[4]	3-D	138%	20	25
[5]	2-D	100%	26	15
[6]	2-D	117%	15	20
This work	2-D	110%	31	30

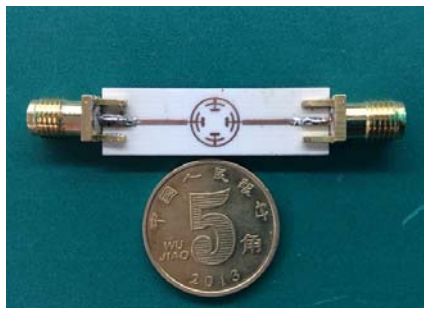

Figure 4. Photograph of the proposed UWB BPF with improved out-of-band rejection.

reported UWB BPFs are listed in Table 1, showing that the proposed UWB filter has good performance. Fig. 4 shows a photograph of the fabricated UWB BPF with improved out-of-band rejection and good selectivity. The overall size is only $23 \times 10\,\text{mm}^2$.

Roll-off rate is defined as $|\alpha_{\max} - \alpha_{\min}|/|f_s - f_c|$, where $\alpha_{\max}$ is the 30 dB attenuation point, $\alpha_{\min}$ the 3 dB attenuation point, f_s the 30 dB stopband frequency and f_c the 3 dB cutoff frequency. Roll-off rate for reported ones is estimated from the figures in papers.

4. CONCLUSION

A new compact UWB BPF has been proposed and designed. To achieve improved out-of-band rejection and good selectivity and size reduction characteristics, four high-low impedance resonant cells are periodically placed in the inner area of a conventional ring MMR. Good agreement between simulation and measurement results demonstrates the validity of the method. The proposed filter is very useful for modern UWB wireless communication systems due to its simple topology, compact size and excellent performance.

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