Progress In Electromagnetics Research Letters, Vol. 45, 25–30, 2014

Compact Microstrip UWB Bandpass Filter with Two Band-Notches for UWB Applications

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Abstract—A new microstrip ultra-wideband (UWB) bandpass filter (BPF) with dual sharply rejected notched bands based on E-shaped resonator is proposed in this paper. The basic UWB BPF is designed using two microstrip interdigital coupled lines and one rectangular patch multiple-mode resonator (MMR). Then, to achieve dual band-notched performance, the proposed dual-mode E-shaped resonator is investigated and coupled to the rectangular patch multiple-mode resonator of the basic UWB BPF. To validate the design theory, a microstrip UWB BPF with two notch-bands centered at the frequencies of 5.8 GHz and 8.0 GHz, respectively, is designed and fabricated. Both simulation and experimental results are provided with good agreement.

1. INTRODUCTION

In 2002, the U.S. Federal Communications Commission (FCC) authorized the unlicensed use of ultra-wideband (UWB, from 3.1 to 10.6 GHz) for a variety of applications, such as indoor and hand-held systems [1]. UWB BPFs, as one of the essential components of the UWB systems, have gained much attention in recent years. There are many methods presented to design UWB bandpass filters [2–10]. For instance, multiple-mode resonator (MMR) [2, 3], defected microstrip structure (DMS) [4], defected ground structure (DGS) [5, 6], multilayer coupled structure [7, 8], and the cascaded low-pass/high-pass filters [9, 10] have been widely used to achieve UWB characteristics.

However, the existing wireless networks such as 5.8 GHz WLAN signals and some 8.0 GHz satellite communication systems signals can interfere with UWB systems, thus compact UWB BPFs with multiple notched bands are emergently required to reject these interfering signals [11–21]. To achieve a notched band, a pair of radial impedance resonators are used in [11], and a stepped impedance resonator is employed in [12, 13]. On the other side, the embedding open-circuited stub is introduced in [14–16], and the wave's cancellation theory is proposed in [17, 18] to block unwanted existing radio signals. However, these methods can only achieve one notched band. Thus, a coupled simplified composite right/left-handed resonator is used in [19], and a novel E-shaped resonator [20, 21] to get two notched bands. However, these two designed methods are all that dual-mode resonator is coupled to the main transmission line of the initial UWB BPF to achieve dual noteched bands. Additionally, double open-circuit stubs are embedded into broadside-coupled stepped impedance resonators on middle layer in [22], and folded stepped impedance resonators are vertically-coupled to the second layer in [23], two notched bands can also be introduced into an UWB BPF. However, they are based on a multilayer structure and hardly compatible with the existing microwave-integrated circuit.

In this paper, we present a new microstrip ultra-wideband (UWB) bandpass filter (BPF) with dual sharply rejected notched bands based on E-shaped resonator is proposed in this paper. The

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Received 15 January 2014, Accepted 7 February 2014, Scheduled 13 February 2014

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design procedures are as following: the basic microstrip UWB BPF is designed using two microstrip interdigital coupled lines and one rectangular patch multiple-mode resonator (MMR). Then, two band-notched performance are achieved by coupling the dual-mode E-shaped resonator to the rectangular patch multiple-mode resonator of the basic UWB BPF. The dual-notched bands can be easily generated and realized by controlling the locations of even-odd modes resonance frequency of the dual-mode stepped impedance resonator. Finally, the proposed filter is designed, fabricated and measured. Good agreement between measured and simulated results is achieved.

2. DESIGN OF UWB BPF WITH NOTCHED BANDS

Figure 1 shows the layout and equivalent circuit network of the designed UWB BPF with dual sharply rejected notched bands. Figure 1(a) comprises of two microstrip interdigital coupled lines and one rectangular patch mutiple-mode resonator (MMR) embedded an E-shaped resonator. By forming quarter-wavelength parallel coupled lines and employing a rectangular patch MMR in the input and output ports, six transmission poles are introduced in the UWB passband to help the constituted filter achieve deeper rejection skirts and wider bandwidths. The equivalent circuit network of the proposed filter is shown in Figure 1(b). The interdigital coupled lines can be equaled as two single transmission lines at two sides and a J-inverter susceptance in the middle. The E-shaped resonator coupled to the rectangular patch MMR section of the basic UWB BPF can be modeled as two shunt series resonant branches.

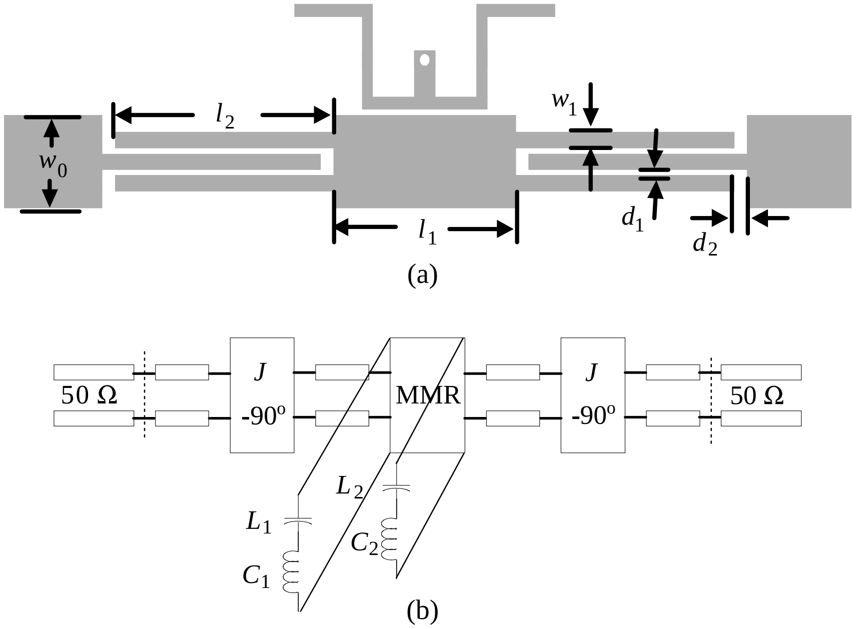

Figure 1. Layout and equivalent circuit network of the UWB BPF with dual notched bands. (a) Layout. (b) Equivalent circuit network.

To realize band-notched characteristics, we introduce an E-shaped resonator into the basic UWB BPF. It should be mentioned that the E-shaped resonator can be equivalent to two shunt-connected series resonance circuit when placed next to the microstrip line, i.e., it can result in dual band-notched performance. This structure is simple and flexible for blocking undesired narrow band radio signals that may appear in UWB band. The introduced E-shaped resonator is composed of a stepped impedance hairpin resonator with centrally loaded a short-ended stub. Figure 2 shows the layout of the E-shaped resonator coupled to the microstrip line and its corresponding equivalent circuit. Since the E-shaped structure is symmetrical to the A-A' plane, the resonance properties of E-shaped resonator can be analyzed by the even-odd modes analysis method. Under mode excitation, the resonator electrical field distribution of the resonator exhibits either an even or an odd mode distribution property as shown in Figure 3. For the odd mode condition, the electrical fields exhibit an anti-symmetric distribution along the A-A' axis and there is no electrical field on the short-end stub as shown in Figure 3(a). While for the even mode, the electrical fields exhibit a symmetric distribution along the A-A' axis and the electrical fields distribute on both the open-end and the short-end stubs of the resonator as shown in Figure 3(b). Thus, based on the electrical field distribution property, the even-odd modes resonance

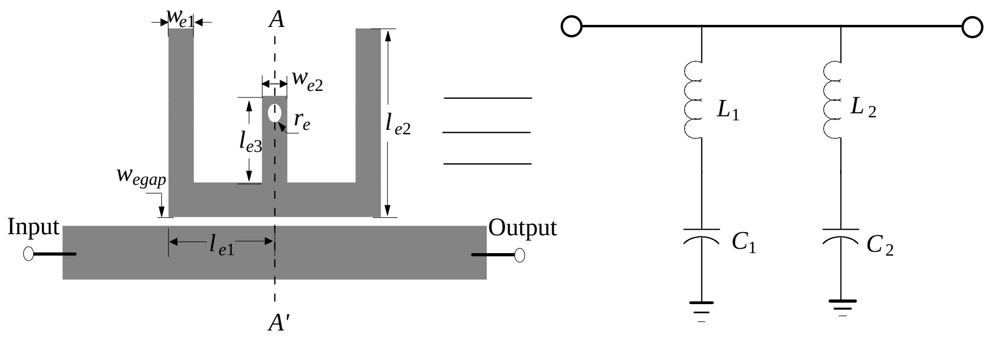

Figure 2. Layout and equivalent circuit of the coupled E-shaped resonator.

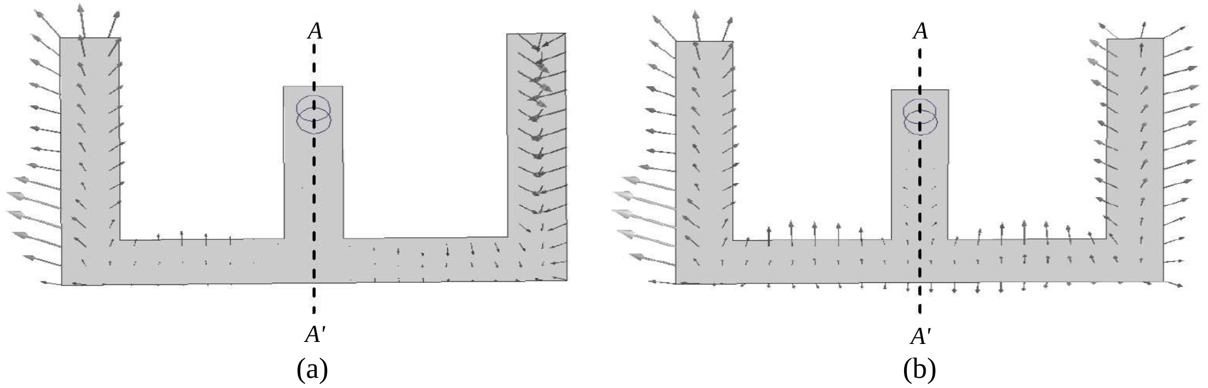

Figure 3. Electrical field distribution of the E-shaped resonator. (a) Odd mode. (b) Even mode.

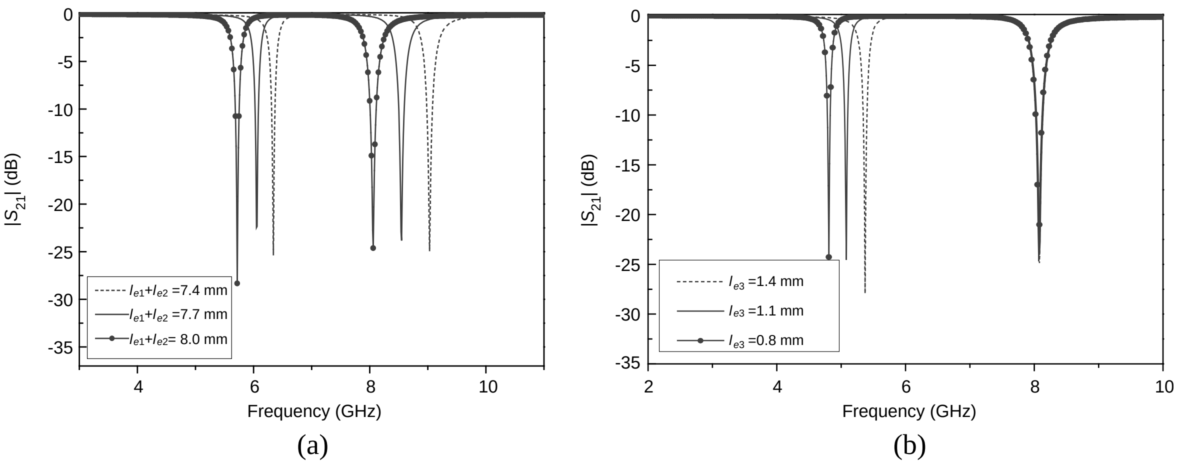

Figure 4. Simulated S-parameters of the coupled E-shaped resonator for various dimensions. (a) $l_{e1} + l_{e2}$. (b) l_{e3}.

frequencies can be expressed as:

$$f_{\text{notch-even}} = \frac{c}{\lambda_{\text{notch-even}}\sqrt{\varepsilon_{\mathit{eff}}}} = \frac{c}{4(l_{e1}+l_{e2}+l_{e3})\sqrt{\varepsilon_{\mathit{eff}}}} \tag{1}$$

$$f_{\text{notch-odd}} = \frac{c}{\lambda_{\text{notch-odd}}\sqrt{\varepsilon_{\mathit{eff}}}} = \frac{c}{4(l_{e1}+l_{e2})\sqrt{\varepsilon_{\mathit{eff}}}} \tag{2}$$

where λ_{notch} is the wavelength of the center frequency of the notched band, f_{notch} is the center frequency of the notched band, $\varepsilon_{\mathit{eff}}$ is the effective dielectric constant, and c is the light speed in free space.

The frequency characteristics of the coupled E-shaped resonator with various dimensions are investigated to validate the dual-mode resonant property as shown in Figure 4. It can be seen that the frequency locations of the two notch-bands move down simultaneously as increase the dimensions of l_{e1}, l_{e2}. This is because the electrical fields distribute on these two areas for both the even and the odd modes. When we decrease l_{e3}, only the frequency location of lower notch-band moves up. This is because there is no electrical fields distribute on the area of l_{e3} for the odd mode. Therefore, by appropriately adjusting the resonator dimensions, dual notched bands can be achieved at desired frequencies.

3. EXPERIMENTAL RESULTS

The UWB BPF has been designed on substrate Rogers RT/duroid 5880 with a dielectric constant of 2.2, thickness of 1.0 mm, and loss tangent of 0.0009. The structural parameters for the optimal UWB BPF circuit are selected as follows: (as illustrated in Figures 1 and 2): $l_1 = 7.0\,\text{mm}$, $l_2 = 8.4\,\text{mm}$, $w_0 = 3.0\,\text{mm}$, $w_1 = 0.5\,\text{mm}$, $d_1 = 0.1\,\text{mm}$, $d_2 = 0.5\,\text{mm}$, $l_{e1} = 2.4\,\text{mm}$, $l_{e2} = 5.6\,\text{mm}$, $l_{e3} = 1.5\,\text{mm}$, $w_{e1} = 0.4\,\text{mm}$, $w_{e2} = 0.8\,\text{mm}$, $w_{egap} = 0.1\,\text{mm}$, and $r_e = 0.2\,\text{mm}$.

Finally, the fabricated UWB BPF is measured with an Agilent N5244A vector network analyzer. Simulated and measured scattering parameters are described in Figure 5 with good agreement. Referring to Figure 5, the fabricated UWB BPF has a passband from 3.0 to 10.3 GHz and the upper-stopband with −10 dB attenuation is up to 16 GHz. The return loss is under −15 dB over most part of the passband. For the two highly rejected notched bands, the measured results show that a better 15 dB insertion loss at 5.8 and 8.0 GHz with the respective 3 dB FBW of 5.9% and 4.2% are achieved. It should be mentioned that the UWB BPF is built up with good insertion loss and return loss for achieving additional six transmission poles in the entire passband. The deviations of the measurements from the simulations are expected mainly due to the reflections from the connectors and the finite substrate. Figure 6 shows the photograph of the fabricated UWB BPF with dual sharply rejected notched bands. The overall size is about $34 \times 14\,\text{mm}^2$.

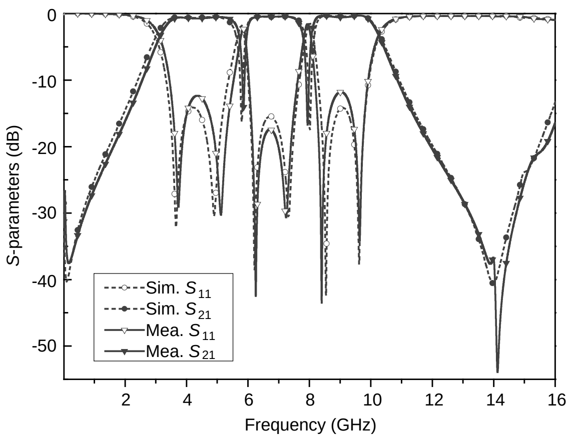

Figure 5. Simulated and measured S-parameters of the designed UWB BPF with dual notched bands.

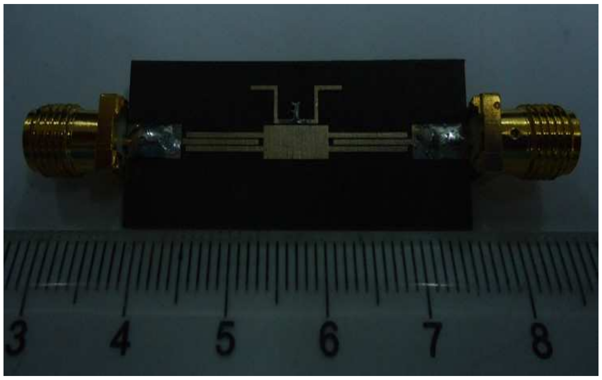

Figure 6. Photograph of the fabricated UWB BPF with dual notched bands.

4. CONCLUSION

A new microstrip UWB BPF with dual highly rejected notched bands has been proposed in this letter. The basic UWB BPF is designed using two microstrip interdigital coupled lines and one rectangular patch MMR. Then, dual-mode E-shaped resonator is investigated and coupled to the rectangular patch multiple-mode resonator of the basic UWB BPF to achieved two notched bands. The two notched bands can be easily generated and realized by controlling the even-odd modes frequency locations of the E-shaped resonator. For demonstration, a microstrip UWB BPF is designed, simulated, and measured. Good agreement between the predicted and measured results is obtained. Therefore, the proposed filter is very useful for modern UWB wireless communication systems owing to its marked properties of simple topology, compact size, and excellent performance.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China under Grant No. 51164033, the Jiangxi province ground plan of science and technology for insitution of higher education No. KJLD12050, the Jiangxi province Science and technology supporting project No. 20123BBE50116, the Jiangxi province Natural Science Foundation of China under Grant No. 20132BAB206021, Scientific Research Fund of Jiangxi province Nos. 12747 and 11739 and 12748, Scientic Research Fund of Hunan Provincial Education Department under Grant No. 13C022, and the Hunan Province Nature Science Foundation of China under Grant No. 14JJ2118.

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