COMPACT UWB FILTER BASED ON SURFACE-COUPLED STRUCTURE WITH DUAL NOTCHED BANDS

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Abstract—A novel compact ultra-wideband (UWB) band-pass filter (BPF) based on surface-coupled structure is proposed. The surface-coupled structures and Y-shaped shorted stub resonator are adopted as quasi-lumped circuit elements to achieve UWB pass-band. To avoid the interference of the wireless local area network (WLAN) at 5.25 and 5.775 GHz, two different quarter-wavelength lines are arranged on the ground of UWB BPF to generate dual narrow stop bands. Being developed from the quasi-lumped elements, the proposed UWB BPFs have very compact size. The fabricated UWB BPFs have the advantages of low insertion loss, good selectivity and flat group delay. Good agreement between equivalent circuit modeled, simulated and measured responses of these filters is demonstrated.

1. INTRODUCTION

The ultra-wideband (UWB) wireless communication technology has received great attention because of the numerous attractive advantages such as transmitting higher data rates and needing lower transmit power. As the key passive components in this system, various UWB band-pass filters (BPFs) with broad passband and good selectivity had been reported in the past. Compared with the UWB BPFs implemented by a direct cascade of the low- and high-pass filters [1], a UWB filter using multimode resonator (MMR) [2–6] has low insertion loss and occupies less circuit. But the sizes of them are usually constrained by the employed MMR structures. Moreover, other techniques were adopted to reduce the size of UWB BPF, such as

defected ground structure [7–9], modified MMR [10, 11] and multilayer circuit [12, 13]. All of the UWB filters mentioned above have exhibited satisfactory performance in the desired wide passband. However, to meet the limit of portable device, the UWB BPF with more compact size and low insertion loss are required.

On the other hand, to eliminate the interference from other existing wireless communication system, such of WiMax and wireless local area network (WLAN), single [14, 15] or multiple [13, 16] narrow-band notched UWB BPFs have been proposed. The reported UWB BPFs with multiple notched bands can provide protection from interference of multiple existing radio systems. However, they are both designed using more than two layers circuit, which results in difficulty of being integrated with planar circuit.

In this article, a novel compact UWB BPF utilizing surface-coupled structure is reported. The surface-coupled structures and Y-shaped shorted stub resonator included in the reported BPF are adopted as the quasi-lumped circuit elements to achieve UWB passband [17]. Compared with those of the published UWB BPFs, the proposed filter shows a significant size and insertion loss reduction. To prevent the interference with the existing WLAN bands, two different quarter-wavelength shorted lines are designed to generate double very narrow stop bands at both 5.25 and 5.775 GHz. The proposed notched technology requires no additional circuit and exhibits much flexibility of design. Moreover, the equivalent circuit models are established to illustrate the frequency responses of the proposed UWB BPFs. Finally, measured results demonstrated good agreement with the circuited and EM-simulated results.

2. DESIGN OF UWB BPF

The proposed UWB BPFs with very compact size comprises several sections of microwave transmission lines (TLs), as shown in Figures 1(a) and (b). A Y-shaped resonator is embedded in the ground, which consists of a short-circuited coplanar waveguide (CPW) stub and two open-circuited micro-coplanar strip (MCS) lines. The surface-coupled structures between the top rectangular plates and the open-circuited MCS lines of the Y-shaped resonator provide sufficiently strong coupling degree in the desired UWB band. Additionally, the short sections in triangular shape inserted between the $50\,\Omega$ line and coupled surface are formed for matching the I/O impedance.

All TLs of the filter can be regarded as quasi-lumped elements since the physical lengths are smaller than $\lambda_g/8$ (λ_g is the guided wavelength of corresponding transmission line at the center frequency

of 6.85 GHz). Hence, the equivalent lumped circuit model can be established for explaining the circuit behaviors more explicitly as shown in Figure 1(c). The rectangular plate with the short section of triangular joint can be modeled as the series inductance L_1 and C_1 with mutual inductance LM_1. The open-circuited stub of the Y-shaped resonator is equivalent to the LC network of L_2, C_2 with the mutual inductance LM_2. The short-circuited CPW stub of the Y-shaped resonator is considered as the LC network of L_3 and C_3. The surface-to-surface couplings between the top patches and Y-shaped resonator are equivalent to the series capacitance of C_4. Moreover, the cross coupling between two plate on the top layer is equivalent to C_5.

Obviously, each element in the equivalent circuit model has a definite relation to the physical dimension of the proposed UWB filter. Thus the frequency responses can be controlled easily. Figure 2 illustrates the EM-simulated S_{21} of UWB BPFs with different w_4 and w_5. Results show that the whole passband of the filter is shifted to
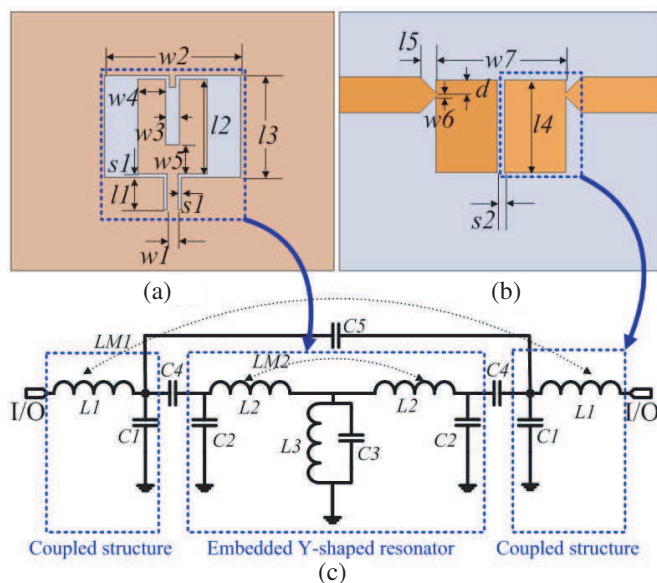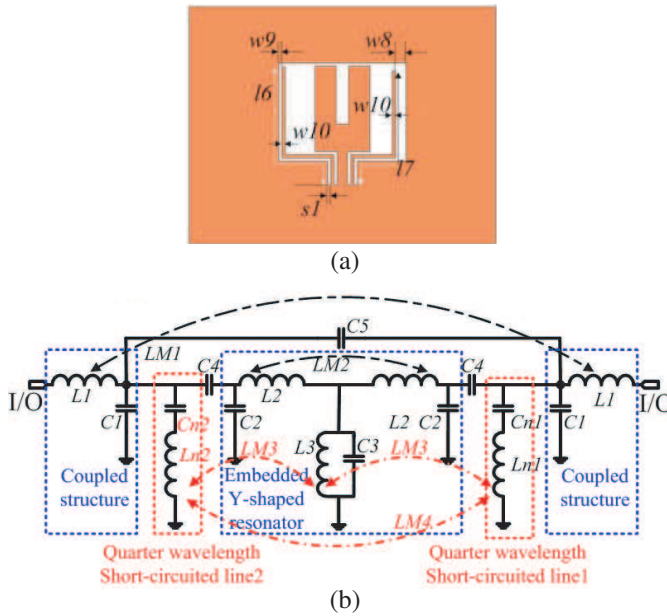

Figure 1. The structure and equivalent circuit model of proposed UWB BPF. (a) Bottom view ($w_1 = 0.66$ mm, $w_2 = 8.5$ mm, $w_3 = 0.86$ mm, $w_4 = 1.5$ mm, $w_5 = 1.8$ mm, $l_1 = 2.02$ mm, $l_2 = 5.86$ mm, $l_3 = 6.1$ mm, $s_1 = 0.22$ mm), (b) top view ($w_6 = 0.22$ mm, $w_7 = 8.02$ mm, $d = 0.75$ mm, $l_4 = 5.74$ mm, $l_5 = 1.02$ mm, $s_2 = 0.46$ mm) and (c) equivalent circuit model ($C_1 = 0.116$ pF, $C_2 = 0.02$ pF, $C_3 = 0.135$ pF, $C_4 = 0.42$ pF, $C_5 = 0.105$ pF, $L_1 = 1.5$ nH, $L_2 = 1.0$ nH, $L_3 = 0.63$ nH, $LM_1 = 1.2$ nH, $LM_2 = 0.432$ nH).

(a)   (b)
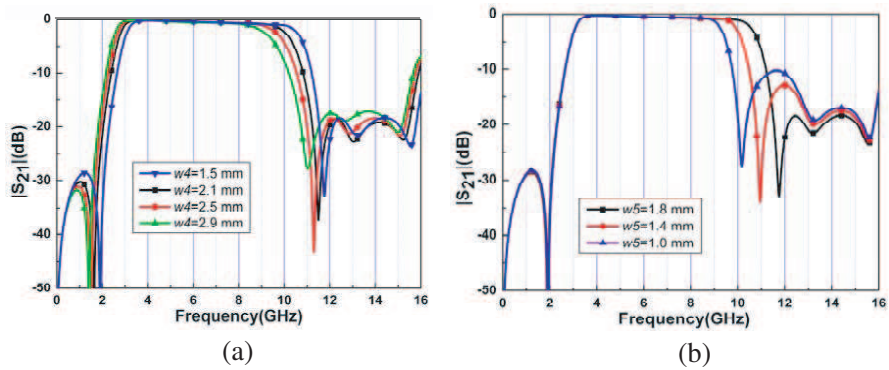
Figure 2. EM-Simulated S_{21} of the proposed UWB BPF with various. (a) w_4 and (b) w_5.

lower frequency when l_4 is increased, whereas fractional bandwidth is almost unchanged, as illustrated in Figure 2(a). Furthermore, when w_5 is decreased from 1.8 to 1.0 mm, the first transmission zero above the UWB band is changed from 11.77 to 10.17 GHz and the second transmission zero is unchanged, while S_{21} at low band keeps the same value, as demonstrated in Figure 2(b). On the other hand, two transmission zeros close to the passband can be controlled by adjusting the cross coupled capacitor of gap. These results demonstrate that the passband and selectivity of the UWB filter are flexible and can be controlled easily.

In order to avoid interference of WLAN at 5.25 and 5.775 GHz, two different quarterwavelength short-circuited lines are arranged on bottom layer to generate double notched bands, as demonstrated in Figure 3(a). The notched frequencies occur at the lengths l_6 and l_7 of about quarter-wavelength. These two lines are modeled by two series Ln_1, Cn_1 and Ln_2, Cn_2 resonators to obtain two different notched bands. However, compared with the UWB BPF without the quarter-wavelength short-circuited lines, the distributed capacitor C_3 is decreased due to the degradation of electric coupling between the CPW stub and ground. Moreover, the magnetic coupling between the CPW stub and the quarter-wavelength short-circuited line can be modeled as the mutual inductance LM_3, and the magnetic coupling of both quarter-wavelength short-circuited lines as the mutual inductance LM_4. The equivalent circuit is illustrated in Figure 3(b). The notched band generated by one quarter-wavelength short-circuited line embedded on the ground can be manipulated by adjusting the lengths of the line, as demonstrated in Figure 4. Thus, dual notched bands can be generated by two lines with different length.

(a)

(b)

Figure 3. The structure and equivalent circuit model of proposed UWB BPF with dual notched bands. (a) The bottom view ($w_8 = 0.72$ mm, $w_9 = w_{10} = 0.22$ mm, $l_6 = 10.8$ mm, $l_7 = 9.8$ mm, $s_3 = 0.22$ mm) and (b) equivalent circuit model ($C_1 = 0.116$ pF, $C_2 = 0.02$ pF, $C_3 = 0.07$ pF, $C_4 = 0.42$ pF, $C_5 = 0.08$ pF, $L_1 = 1.5$ nH, $L_2 = 1.0$ nH, $L_3 = 0.66$ nH, $LM_1 = 1.2$ nH, $LM_2 = 0.432$ nH, $LM_3 = 0.87$ nH, $LM_4 = 0.57$ nH, $Cn_1 = 0.045$ pF, $Cn_2 = 0.05$ pF, $Ln_1 = 18.5$ nH, $Ln_2 = 20$ nH).
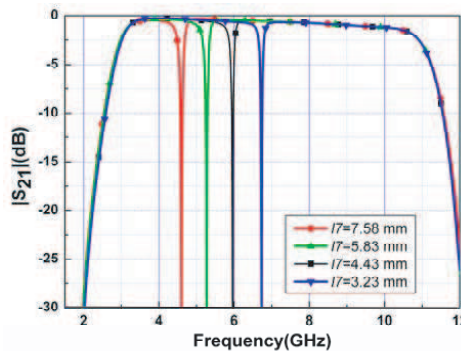

Figure 4. EM-Simulated S_{21} of the proposed one-notched UWB BPF with various lengths l_7 of the short-circuited line.

3. RESULTS AND DISCUSSION

The proposed UWB BPFs are fabricated on substrate with relative dielectric constant $\varepsilon_r = 2.55$, loss tangent $\delta = 0.002$ and thicknesses $h = 0.8\,\mathrm{mm}$, as shown in Figure 5. The dimensions of the UWB BPFs are listed in the caption of Figure 1 and Figure 3.
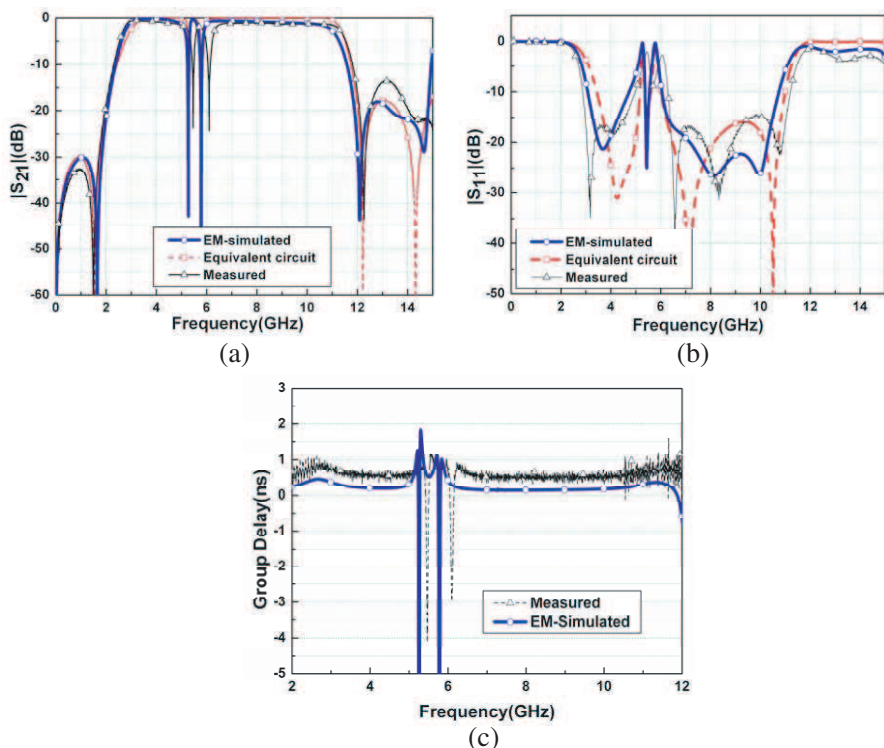
The EM-simulated, equivalent-circuit modeled, and measured S-parameters and group delay of the proposed UWB BPF without notched band are plotted in Figure 6, and a good agreement among them is observed. The measured in-band insertion loss is $0.46\,\mathrm{dB}$ and the 3 dB fractional bandwidth is 110% from 3.05 to 10.5 GHz with three-pole response. Three transmission zeros are found at 1.8, 11.7, and 15.5 GHz, which demonstrates that the filter possesses a good selectivity at passband edges and has a stopband with about 15 dB attenuation from 11.1 to 16.5 GHz. The flat group delay is also plotted in Figure 6. The measured variation of group delay within the passband is less than 0.32 ns. The UWB filter has a compact size

(a)   (b)
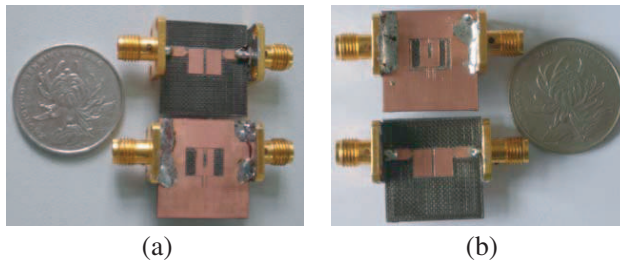
Figure 5. The photos of fabricated UWB filters. (a) Without notched band, (b) with dual notched bands.
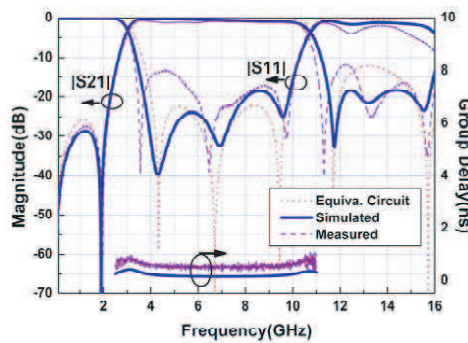
Figure 6. EM-Simulated, equivalent-circuit modeled and measured S-parameters and group delay of the proposed UWB BPF.

Figure 7. EM-Simulated, equivalent-circuit modeled and measured. (a) S_{21}, (b) S_{11} and (c) group delay of the proposed UWB BPF with dual notched bands.

of 10.2 mm by 8.3 mm corresponding to $0.34\lambda_g$ by $0.27\lambda_g$. Moreover, the parameters of the equivalent circuit are determined by fitting the full-wave simulated results, and these values are listed in the caption of Figure 1.

Figure 7 plots the full-wave simulated, equivalent-circuit modeled, measured S-parameters and group delay of the proposed dual-notched UWB BPF. The measured in-band insertion losses are 0.49 and 0.98 dB at the center frequencies of the two passbands, i.e., 4.2 and 7.8 GHz. Moreover, both narrow stop bands at 5.27–5.59 and 5.89–6.30 GHz can be obtained by inserting two short-circuited lines. The measured centre frequencies of the notched bands are slightly shifted to higher frequencies and the insertion loss of implemented BPF are little higher than the simulated results. They could attribute to the fabricated tolerance and the losses of SMA connectors. Figure 7(c) shows that the group delay is almost flat except the two notched bands in UWB band. The remarkable variation in the group delay is mainly due to

the sharp rejection edge around the notched bands. The notched UWB filter also has a compact size of $0.34\lambda_g$ by $0.27\lambda_g$.

4. CONCLUSION

The compact UWB BPFs based on surface-coupled structure have been proposed and investigated through simulations and experimentally. Results reveal that the proposed UWB BPF with very compact size achieves low insertion loss, good selectivity at both low and high passband edges and flat group delay. By adding two short-circuited lines on the ground, two narrow notched bands have been achieved with no additional circuit. The proposed UWB BFP's compact size and low insertion loss therefore make it well suited for portable applications.

ACKNOWLEDGMENT

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