LETTER

Design of Compact Ultra-Wideband Filter with Low Insertion Loss and Wide Stopband

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SUMMARY This paper proposes a compact ultra-wideband filter, which skillfully utilizes the magnetic and capacitive coupling to obtain sharp rejection. And, the filter contains a small number of lossy elements, thus the low insertion loss and compact size will not be compromised. The measured results show that the filter prototype has a measured 3 dB fractional bandwidth of 128% from 2.8 GHz to 11.4 GHz, a minimum insertion loss of 0.3 dB within the passband, a superior 20 dB stopband rejection from 12.4 GHz to 24 GHz, and a very compact circuit size of $0.23\lambda \times 0.31\lambda$, where λ is the guided wavelength of the microstrip structure at the center frequency $f_0 = 7.1$ GHz.

key words: *wideband, wide-stopband, selectivity, compact*

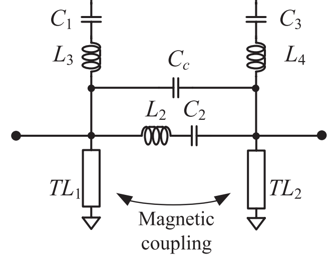
1. Introduction

The wide-band band-pass filter is a critical component since the Federal Communications Commission (FCC) in the USA released the unlicensed use of UWB band (3.1–10.6 GHz) for a variety of applications in 2002. Among the different design approaches, filters that use parallel-coupled lines with patterned ground were employed to give a tight coupling for wideband applications [1]. However, owing to the stringent requirement of large fractional bandwidth, a very small gap size is demanded to enhance the coupling, which is not easy to be fabricated. One way to relieve the restriction on gap size is to add a third line in the parallel coupled-line filter; unfortunately, the necessary gap size is still too narrow for fabrication [2]. Another way to achieve wideband characteristics is to adopt multimode resonators, but the gap size problem still remains [3]–[5]. Additionally, these filters have low insertion loss but may lead to poor spurious response. A high-pass-based band-pass filter using a microstrip-coplanar-waveguide structure has been proposed to achieve wideband characteristics [6]; however, the resulting poor spurious response leaves room for improvement. To suppress such spurious response, a quasi-lumped and electromagnetic bandgap structure was also applied to improve the stopband rejection; however, the circuit size and insertion loss can still be minimized further [7]–[10].

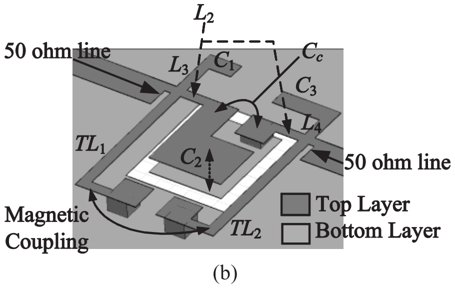
This letter proposes a compact ultra-wideband filter with low insertion loss, wide stopband, and compact size. A wideband filter was then designed and fabricated using Rogers RO4003C (with $\varepsilon_r = 3.38$, $\tan\delta = 0.0027$, and thickness $h = 0.508$ mm). Important parameters such as passband insertion loss, stopband bandwidth, stopband rejection, and size will all be measured and compared with filters designed by other research groups.

2. Wideband Filter Design

Figure 1(a) shows the proposed quasi-lumped band-pass filter prototype containing three inductors, four capacitors, and two short circuited shunt stubs. The resonant frequency of the series circuit L_2C_2 is 7 GHz, and that of C_1L_3 and C_3L_4 is about 17 GHz. The two short circuited shunt stubs TL_1 and TL_2 are quarter-wavelength at about 9.5 GHz, and C_1L_3 and C_3L_4 will resonate with $TL1$ and $TL2$ at the center frequency of the passband, i.e. 7 GHz. Thus, the prototype originates from a high-pass circuit at low frequency, and then transforms into a low-pass one at high frequency; therefore the wide passband characteristic can be obtained [11]. For the stopband characteristic, C_c can produce a transmission zero close to the upper passband edge, thus a good selectivity can be obtained. Furthermore, the series circuits L_3C_1 and L_4C_3 and the two short circuited shunt stubs TL_1 and TL_2 that are half-wavelength at 18 GHz will enhance the upper stopband rejection. For the lower stopband rejection, the magnetic



(a)



(b)

Fig. 1 (a) The proposed wideband filter. (b) The three-dimensional layout.

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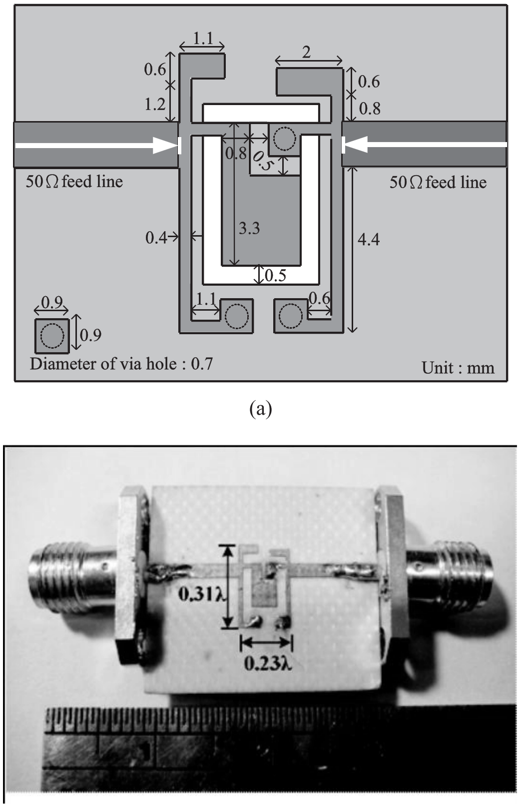
coupling between TL_1 and TL_2 will produce a transmission zero [12].

In our implementation, quasi-lumped elements are adopted to approximate the quasi-lumped prototype. As depicted in Fig. 1(b), the inductors L_2, L_3 and L_4 are implemented by high-impedance microstrip line sections, and the shunt transmission lines TL_1 and TL_2 are implemented by microstrip shorted stubs connected to ground. The capacitors C_1 and C_3 are implemented by low-impedance microstrip line sections and the series capacitor C_2 is realized by the microstrip-to-CPW transition. Besides, C_c originates from the microstrip-to-CPW transition, thus its layout including the slot in the bottom layer and the gap in the top layer should be simulated carefully. Furthermore, the capacitive coupling between C_1 and C_3 will affect C_c, thus the distance between those capacitors should be desinged suitably to optimize the selectivity of the filter. The filter skillfully utilizes the capacitive and magnetic coupling between the elements implemented in the three- dimension layout, thus we can obtain good selectivity with a small number of passive/lossy elements. Furthermore, because a small number of passive/lossy elements are used, low insertion loss over the wide passband and compact size won't be compromised.

3. Experimental Results

To verify the feasibility of the quasi-lumped prototype and to account for the discontinuities between the elements which are not considered in the prototype, the filter is simulated over its entire layout using Ansoft HFSS v10 and is then fabricated using Rogers RO4003C (with $\varepsilon_r = 3.38$, $\tan\delta = 0.0027$, and thickness $h = 0.508$ mm). Figure 2(a) shows the top-/bottom-layer layout, and the photograph of the proposed filter is shown in Fig. 2(b). The overall dimension of the device is 4.6 mm × 7.4 mm, which is approximately $0.23\lambda \times 0.31\lambda$, where λ is the guided wavelength of the microstrip structure at the center frequency f_0 = 7.1 GHz. The dimensions confirm the very compact size of the developed device. Figure 3 shows the measured S-parameters of the proposed wideband filter. The filter has a measured 3 dB fractional bandwidth of 128% from 2.8 GHz to 11.4 GHz. The return loss is greater than 13 dB within the pass-band, and the minimum insertion loss is 0.3 dB at 5 GHz. It also exhibits good selectivity and stopband rejection, which is better than 20 dB from 12.4 GHz to about 24 GHz. The discrepancies between the simulated and measured results are due to the fabrication errors. Moreover, from the measured S-parameters, we determine that the implemented filter exhibits a flat group-delay ranging from 0.32 ns to 0.44 ns over the whole passband, as shown in Fig. 4. Comparison with other filters is summarized in Table 1. In terms of size, stopband rejection, stopband bandwidth and insertion loss, our wideband filter has similar or better performance.



(a)

(b)

Fig. 2 (a) The top-/bottom-layer circuit layout of the proposed filter. (b) The photograph of the filter.

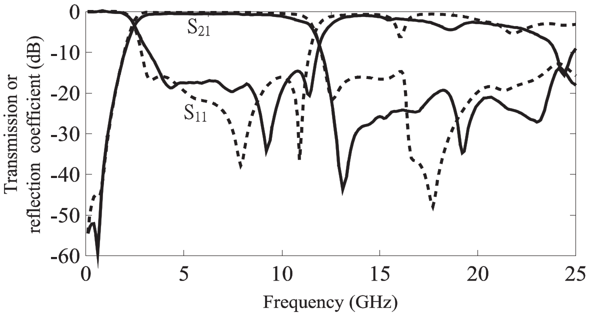


Fig. 3 Simulated (dashed curves) and measured (solid curves) insertion loss, and return loss of the fabricated filter.

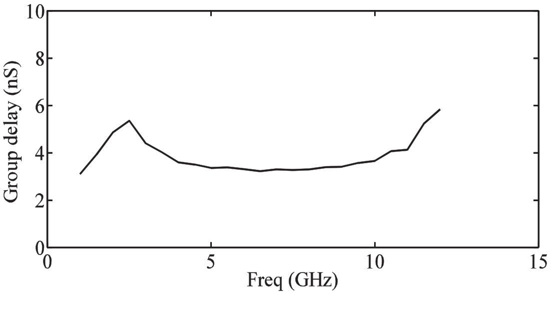


Fig. 4 Measured group delay of the fabricated filter.

Table 1 Performance comparison of filters presented in prior works and the proposed filter.

	3dB BW (GHz)	Min. Return Loss (dB)	Min. Insertion Loss (dB)	Stopband Rejection / Bandwidth (GHz)	Size	ε_r / tanδ	Design method
[6]	3.18-10.72	17.2	0.48	20 / 11-15	0.306 × 0.458 λ	3.38 / 0.0027	Quasi-lumped
[7]	3-10	13	1*	20 / 12.6-26.9	0.45 λ × 1.76 λ	3.38 / 0.0027	Quasi-lumped
[8]	1-5.8	10	0.9	30 / 6.4-20	0.28 λ × 0.59 λ	2.4 / NA	Electromagnetic bandgap
[9]	1.8-10	10	0.32	38 / 10.4-18	0.36 λ × 0.87 λ	3.15 / 0.0025	Quasi-lumped
[10]	2.8-11	15	1.1*	30 / 12-30	0.44 λ × 0.6 λ	10.8 / 0.0023	Multi-mode resonator
This work	**2.8-11.4**	**13**	**0.3**	**20 / 12.4-24**	**0.23 λ × 0.31 λ**	**3.38 / 0.0027**	Quasi-lumped

*Maximum Insertion Loss

4. Conclusions

In this paper, a 2.8–11.4 GHz filter was designed and fabricated using Rogers RO4003C (with $\varepsilon_r = 3.38$, $\tan\delta = 0.0027$, and thickness $h = 0.508$ mm). Compared with other filters in a similar frequency range, our circuit simultaneously achieves low insertion loss, wide-stopband, good selectivity, and compact size.

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References

[1] W. Menzel, L. Zhu, K. Wu, and F. Bögelsack, “On the design of novel compact broadband planar filters,” IEEE Trans. Microw. Theory Tech., vol.51, no.2, pp.364–369, Feb. 2003.

[2] J.-T. Kuo and E. Shih, “Wideband bandpass filter design with three-line microstrip structures,” IEEE MTT-S Int. Dig., pp.1593–1596, 2001.

[3] L. Zhu, S. Sun, and W. Menzel, “Ultra-wideband (UWB) bandpass filters using multiple-mode resonator,” IEEE Microw. Wireless Compon. Lett., vol.15, no.11, pp.796–798, Nov. 2005.

[4] H. Wang, L. Zhu, and W. Menzel, “Ultra-wideband bandpass filter with hybrid microstrip/CPW structure,” IEEE Microw. Wireless Compon. Lett., vol.15, no.12, pp.844–846, March 2005.

[5] J. Gao, L. Zhu, W. Menzel, and F. Bögelsack, “Short-circuited CPW multiple-mode resonator for ultra-wideband (UWB) bandpass filter,” IEEE Microw. Wireless Compon. Lett., vol.16, no.3, pp.104–106, March 2006.

[6] T.-N. Kuo, S.-C. Lin, and C.H. Chen, “Compact ultra-wideband bandpass filters using composite microstrip-coplanar-waveguide structure,” IEEE Trans. Microw. Theory Tech., vol.52, no.10, pp.3772–3778, Oct. 2006.

[7] C.-W. Tang and M.-G. Chen, “A microstrip ultra-wideband bandpass filter with cascaded broadband bandpass and bandstop filters,” IEEE Trans. Microw. Theory Tech., vol.55, no.11, pp.2412–2418, Nov. 2007.

[8] J. Garcia-Garcia, J. Bonache, and F. Martin, “Application of electromagnetic bandgaps to the design of ultra-wide bandpass filters with good out-of-band performance,” IEEE Trans. Microw. Theory Tech., vol.54, no.12, pp.4136–4140, Dec. 2006.

[9] Z.-C. Hao and J.-S. Hong, “Ultra-wideband bandpass filter using multilayer liquid-crystal-polymer technology,” IEEE Trans. Microw. Theory Tech., vol.56, no.9, pp.2095–2100, Sept. 2008.

[10] S.W. Wong and L. Zu, “Quadruple-mode UWB bandpass filter with improved out-of-band rejection,” IEEE Microw. Wireless Compon. Lett., vol.19, no.3, pp.152–154, March 2009.

[11] D. Pozar, Microwave Engineering, Wiley, New York, 2005.

[12] T. Ishizaki, M. Fujita, H. Kagata, T. Uwano, and H. Miyake, “A very small dielectric planar filter for portable telephones,” IEEE Trans. Microw. Theory Tech., vol.42, no.11, pp.2017–2022, Nov. 1994.