A Compact Diplexer Composed of Quarter-wavelength Resonators for Ultra-wideband (UWB) System

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Abstract— A compact diplexer composed of quarter-wavelength resonators for ultra-wideband (UWB) system is proposed and implemented in this paper. The microstrip diplexer is mainly composed of two bandpass filters, which operates at 3.1–5.0 GHz (namely L-BPF) and 6.2–10.1 GHz (namely H-BPF), respectively. Each filter is composed of three shorted-circuit quarter -wavelength resonators. After optimizing the performance, the highest return loss of each filter in the desired passband is -14 dB and -16.8 dB, respectively. For both filters, the insertion loss is below 1 dB and the wide stopband rejection is greater than 20 dB. The isolation between two channels is more than 25 dB. The design concept is proposed in detail and has been verified by the experimental results of a fabricated diplexer. The size is compact with overall dimensions of $19.5 \times 19 \times 0.8\,\text{mm}^3$.

1. INTRODUCTION

In the existing communication systems, diplexer is one of the essential component building blocks that is widely used in transceiver and mixer applications to isolate two or more frequencies [1, 2]. Diplexers are three terminal devices that take two or more frequencies into one port and separate them to two output ports. Diplexers can be constructed by different filter configurations such as lowpass and highpass filters, two bandpass filters, and bandpass and bandstop filters [3]. In the composition of filters, resonator cell is the key part. In the past, numerous kinds of resonator cell have been proposed, such as open-loop ring resonator [4], stepped impedance coupled-line resonator [5], open-circuited periodic stubs [6], hairpin line resonator [7]. In [8], quarter-wavelength resonator is proposed to construct interdigital bandpass filter. In this way, quarter-wavelength resonator can be used to design diplexers with good performance.

On the other hand, to avoid the frequency use of 5–6 GHz for IEEE 802.11a wireless networks (WLANs), the direct sequence ultra-wideband (DS-UWB) specifications for wireless personal area network (WPANs) need to divide into a low band of 3.1–5.0 GHz and a high band of 6.1–10 GHz. Thus, designing diplexers satisfy the desired operation band is necessary.

In this paper, a compact diplexer composed of quarter-wavelength resonators is introduced. The diplexer is constructed by two bandpass filters and each bandpass filter is composed of three identical quarter-wavelength resonators. Each resonator is short-circuited at one end and open-circuited at the other end. The advantages of the diplexer is compact, low insertion loss, good out-of-band performance and covering the desired operation band in ultra-wideband (UWB) systems.

2. DESIGN OF DIPLEXER

Figure 1 shows the structure of the design diplexer. The primary structures are lower passband filter (L-BPF) operating at 3.1–5.0 GHz and higher passband filter (H-BPF) operating at 6.2–10.1 GHz, respectively. Each BPF is composed of three identical quarter-wavelength resonators (with respect to each central frequency at 4 GHz and 8 GHz, respectively). Each resonator is short-circuited at one end and open-circuited at the other end. Port 1 is the input port with impedance of 50 Ω and the microstrip feed line is coupled to two resonators tightly. Each resonator is coupled tightly to each other to form strong coupling and compact structure. Two structure parameters, spacing (s) between resonators and gap (g) between I/O ports and resonator are extracted to control coupling coefficient and quality factor, respectively. The diplexer is designed on PCB with dielectric constant of 2.55, substrate thickness of 0.8 mm and loss tangent of 0.003.

An electromagnetic (EM) simulator Aglient Technologies' 2013 Advance Design System (ADS) is used to extract coupling coefficient (k) between two resonators. The coupling coefficient (k) is controlled by the resonator spacing (s) as shown in Fig. 2(a). The coupling between resonators can

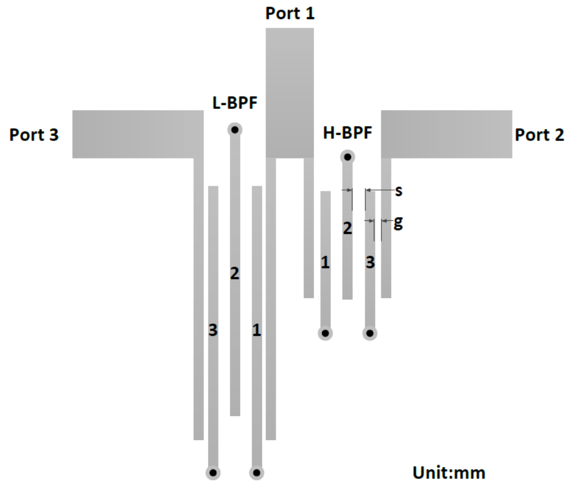

Figure 1: Practical layout of the design diplexer.

be specified by the two dominant resonant modes, which are split off from the resonance condition. The simulated coupling coefficient $K_{i,i+1}$ between the resonator i and $i+1$ ($i = 1, 2$) as functions of spacing (s) is calculated as [8]

$$K_{i,i+1} = \frac{f_H^2 - f_L^2}{f_H^2 + f_L^2} \tag{1}$$

where the f_H is the higher frequency of the two resonant modes, and f_L be the lower one. It is noted that K_{12} and K_{23} are all subjected to an offset s. When s value is reducing, the coupling coefficient would be increased, namely the two resonant modes can be largely separated.

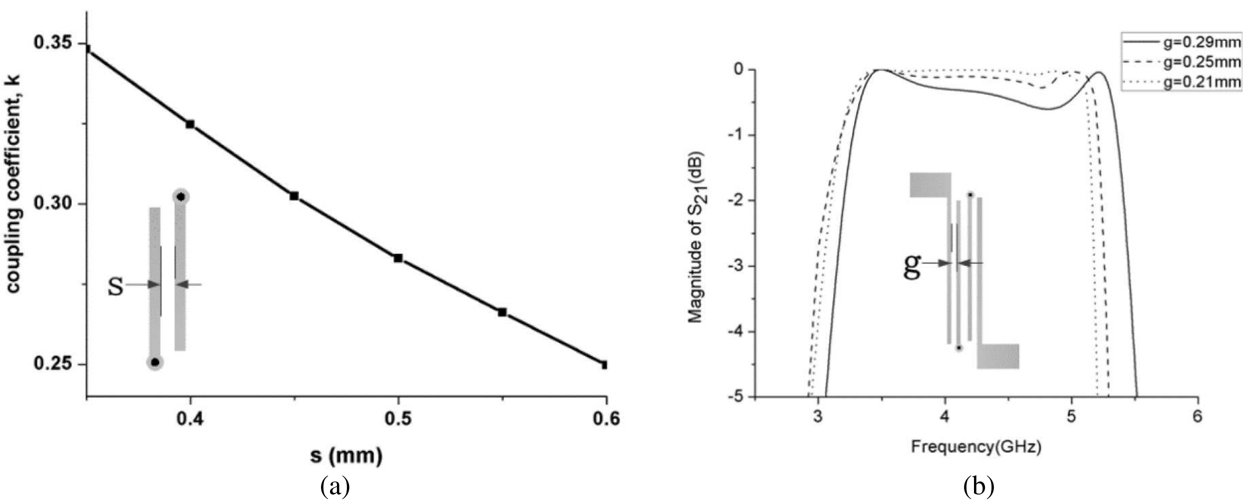

Figure 2: (a) Calculated coupling coefficient between resonators with different spacing, (b) the simulated frequency response with different gaps between the resonator and the I/O ports ($s = 0.43$ mm).

On the other hand, to achieve the balanced passband behavior, namely without ripple in the passband, a strong coupling level between I/O ports and the resonators is needed. As shown in Fig. 2(b), the simulated performances of a pair of resonators are discussed as functions of different gap (g). As the spacing (s) is fixed at 0.43 mm and the gap is reduced, the coupling strength would be enhanced. The smaller the gap (g), the better the passband performance. When the gap (g) is reduced to 0.21 mm, the unbalanced passband level Δ_{dB} is less than 0.1 dB ($\Delta_{\mathrm{dB}} = |S_{21(\max)}| - |S_{21(\min)}|$ in the passband), this implies a low passband ripple. Moreover, such small gap ($g = 0.21$ mm) is still available using the conventional carving machine, without using the expensive lithography process. Therefore, gap of $g = 0.21$ mm would be optimum design condition for both H-BPF and L-BPF in this paper.

The three-pole ($n = 3$) Chebyshevlow pass prototype with a passband ripple of 3 dB is chosen for H-BPF and L-BPH, both with a FBW of 50% at center frequency 4 GHz and 8 GHz, respectively. The lowpass prototype parameters are $g_0 = g_4 = 1$, $g_1 = g_3 = 3.3487$, $g_2 = 0.7117$. Thus, theoretical coupling coefficient $M_{i,i+1}$ is obtained as $M_{1,2} = M_{2,3} = 0.324$, calculated by using [8]

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \tag{2}$$

According to Fig. 2(a), when the coupling coefficient is 0.324, then the spacing (s) is about 0.45 mm, so the theoretical spacing $s_{i,i+1}$ between resonator i and $i+1$ is $s_{1,2} = s_{2,3} = 0.45$ mm. After optimizing the structure, the final design spacing is $s = 0.54$ mm for L-BPF and $s = 0.56$ mm for H-BPF, respectively. Moreover, the length of each resonator is 11.9 mm for L-BPF and 5.8 mm for H-BPF, respectively. The design input/output impendence are all 50 Ω and the radius of via is 0.3 mm. The size is compact with overall dimensions of $19.5 \times 19 \times 0.8\,\text{mm}^3$.

3. SIMULATION AND EXPERIMENT RESULTS

The microstrip diplexer was fabricated using the carving machine and then measured by an Advantest R3770 vector network analyzer over the frequency range from 0 to 11 GHz. Figs. 3(a)–(d) show the simulated and measured results of the diplexer. As expected, there are three modes in each passband and the measured results show a good agreement with the simulated result. As shown in Fig. 3(c), for the lower passband filter, the center frequency is 4.1 GHz and 3 dB bandwidth is 3.17–5.06 GHz (FBW = 46.1%). The maximum return loss in the passband is −14 dB for the

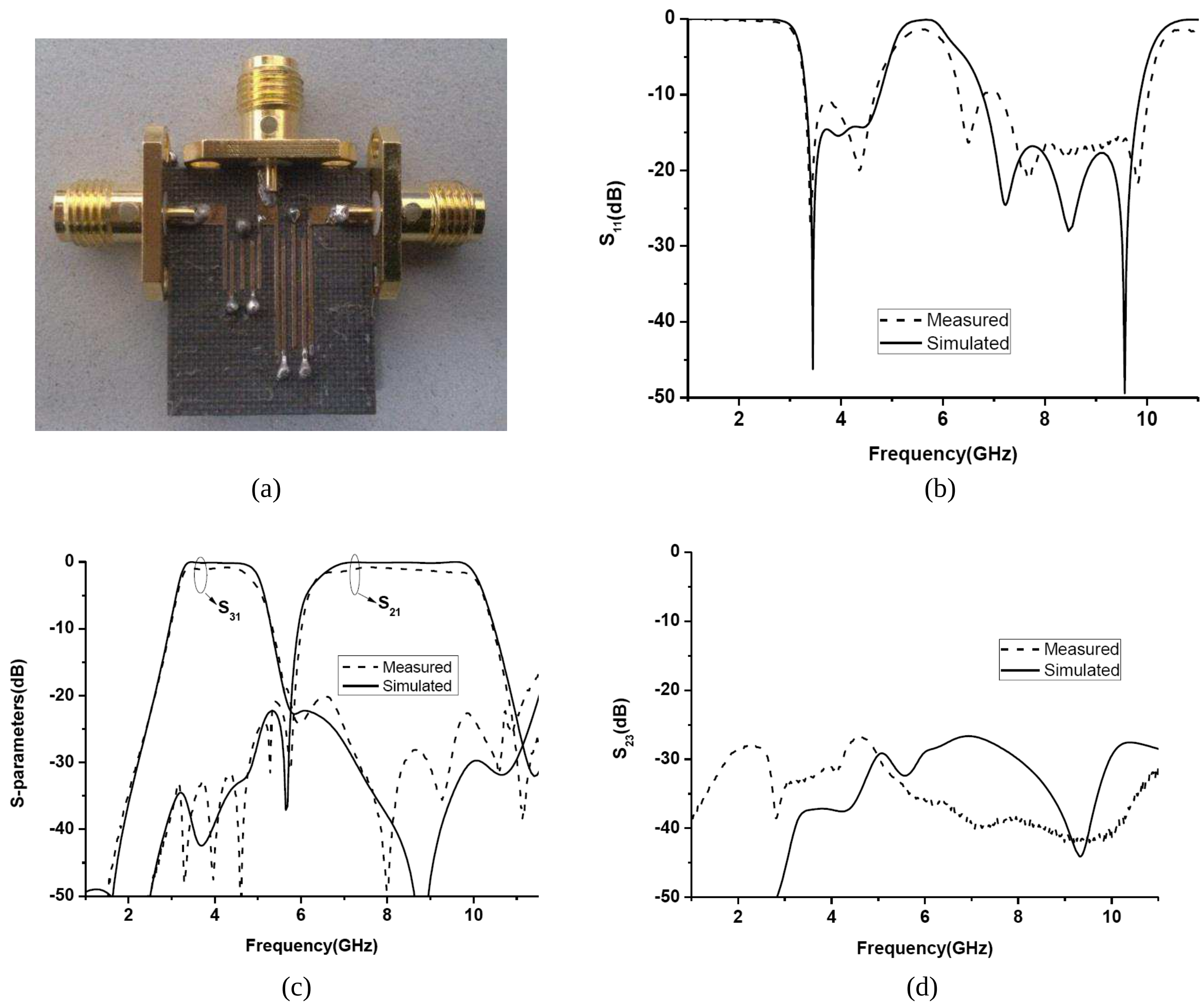

Figure 3: Measured and simulated results of the diplexer: (a) picture of fabricated diplexer, (b) S_{11}, (c) S_{21} and S_{31}, (d) S_{23}.

simulated result and -10.8 dB for the measured result, respectively. The measured insertion loss S_{21} is less than -1.2 dB and the wide stopband rejection is greater than 20 dB from 5.6–11 GHz. For the lower passband filter, the center frequency is 8.1 GHz and 3 dB bandwidth is 6.2–10.1 GHz (FBW = 48.1%), the maximum return loss in the passband is -16.8 dB for the simulated result and -9.4 dB for the measured result, respectively. The measured insertion loss S_{21} is less than -1.5 dB and the wide stopband rejection is greater than 20 dB from 1–5.8 GHz. From Fig. 3(d), it can be observed that the isolation between two channels is more than 25 dB. The measured results verified the proposed design concept. In addition, the overall dimension is $19.5 \times 19 \times 0.8\,\mathrm{mm}^3$, which is compact and low cost to fabricate.

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REFERENCES

1. Yun, T.-Y., C. Wang, P. Zepeda, C. T. Rodenbeck, M. R. Coutant, M.-Y. Li, and K. Chang, "A 10- to 21 GHz, low-cost, multifrequency, and full-duplex phased-array antenna system," *IEEE Trans. Antennas Propaga.,* Vol. 50, No. 5, 641–650, May 2002.
2. Shimozawa, M., T. Katsura, N. Suematsu, K. Itoh, Y. Isota, and O. Ishida, "A passive-type even harmonic quadrature mixer using simplefilter configuration for direct conversion receiver," *IEEE MTT-S Int Microwave Symp.*, 11–16, Boston, MA, 2000.
3. Weber, R. J., *Introduction to Microwave Circuits Radio Frequency and Design Applications*, 248–252, IEEE Press, New York, 2001.
4. Hsieh, L.-H. and K. Chang, "New microstrip diplexer using open-loop ring resonators with two transmission zeros," *Microw. Opt. Technolo. Lett.*, Vol. 44, No. 5, 396–398, Mar. 5, 2005.
5. Srisathit, S., S. Patisang, R. Phromloungsri, S. Bunnjaweht, S. Kosulvit, and M. Chongcheawchamnan, "High isolation and compact size microstriphairpin line diplexer," *IEEE Microw. Wireless Compon. Lett.,* Vol. 15, No. 2, 101–103, Feb. 2005.
6. Strassner, B. and K. Chang, "Wide-band low-loss high-isolation microstripperiodic-stub diplexer for multiple-frequency applications," *IEEE Trans. Microw. Theory Tech.*, Vol. 49, No. 10, 1818–1820, Oct. 2001.
7. Weng, M. H., C. Y. Hung, and Y.-K. Su, "A Hairpin line diplexer for direct sequence ultra-wideband wireless communications," *IEEE Microw. Wireless Compon. Lett.,* Vol. 17, No. 7, 519–521, Jul. 2007.
8. Hong, J. S. and M. J. Lancaster, *Microstrip Filters for RF/Microwave Application*, Wiley, New York, 2001.