Fabrication of a Novel Diplexer Using Folded Open-Loop Ring Resonators and Microstrip Lines

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Abstract **─** A simple and novel low-loss diplexer with two folded Open-Loop Ring Resonators (OLRRs) that couple three microstrip lines is proposed. The first passband and second passband of the designed diplexer could be easily and accurately shifted to a desired frequency and construct the bandpass filters by adjusting the physical dimensions of the OLRRs. These results suggested that the proposed diplexer had the frequency-adjustable characteristics. The longer OLRR is placed between the upper and middle microstrip lines to generate a 2.4 GHz resonant frequency and the shorter OLRR is placed between the middle and lower microstrip lines to generate a 5.2 GHz resonant frequency. By adjusting the positions of the two OLRRs, the resonant frequencies can be tuned.

Index Terms **─** Diplexer, microstrip lines, microwave components, Open-Loop Ring Resonator (OLRR), standing wave.

I. INTRODUCTION

Modern wireless communication systems require radio-frequency devices operating in multiple frequency bands. Planar diplexer with compact circuit size, low insertion loss, high isolation, and flexible passband frequencies is an important component in the multi-band and multi-service wireless communication systems. Low-cost microstrip diplexers can be easily mounted on a dielectric substrate and allow for flexible circuit layout design [1]. Many studies have attempted to reduce the size and improve the performance of microstrip diplexers [2-10].

To reduce size, many complex resonators, such as stepped-impedance open-loop resonators [2], miniaturized open-loop resonators [3], square open-loop with stepped-impedance resonators [4], stepped-impedance coupled-line resonators [5], H-type resonators [6], and artificial transmission lines [7] have been utilized in diplexer design. In [8], a compact diplexer based on double-sided parallel microstrip lines was developed, but it requires a multilayer structure. In [9], a microstrip electromagnetic band gap structure was used to obtain a wide stopband of the diplexer, but the selectivity was poor. In [10], the diplexer with resistor-loaded resonator can suppress harmonics near the two passbands. The performance of microstrip diplexers is also important. However, the above diplexers have one or more performance problems, such as low selectivity, low isolation, large harmonic suppression, and fixed frequency ratio range of the two passbands. In addition, their circuits have problems such as high complexity,

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sensitivity to the dimensions of designed patterns, and difficulty of duplication.

A folded coupled-line structure and dual-mode stripline ring resonators have been utilized to produce transmission zeros to improve the selectivity of diplexers [11,12]. If the unloaded quality factor of harmonics can be greatly reduced, the harmonics can be well suppressed. For diplexers with a wide stopband, it is easy to control the frequency ratio of the two passbands of the diplexer, because the harmonic of the lower passband is far from that of the higher passband, and thus, adjusting one does not affect the other. OLRRs have been applied to planar bandpass and bandstop filter design [13,14].

In the present study, a novel and simple low-loss diplexer with two folded Open-Loop Ring Resonators (OLRRs) with different physical dimensions that couple three microstrip lines, shown in Fig. 1, is proposed. Each OLRR is placed between two microstrip lines and has a perimeter of about a half wavelength of the designed resonant frequency. Each of the fold OLRRs has its maximum electric field density near the open ends of the line and has its maximum magnetic field density around the center valley of the line at resonance. The resonant frequencies can be adjusted via the length of the OLRRs to provide a high-performance passband response. The proposed diplexer has low insertion loss, a wide tunable range of either passband, transmission zeros, simple design, and no external impedance-matching block. A high-performance diplexer with dual-band frequencies of 2.4/5.2 GHz for WLAN band system is designed here to demonstrate the proposed structure.

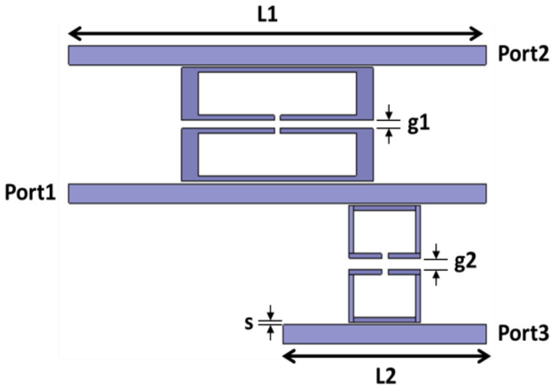


Fig. 1. Proposed diplexer based on OLRRs.

II. DESIGN METHODOLOGY

The diplexer with dual-band frequencies of 2.4/5.2 GHz for WLAN band system is designed here to demonstrate the proposed structure. In the past, the diplexer using OLRRs was accompanied by using the discriminating coupling technique [15-17]. Each of the open-loop ring resonators is essentially a folded half-wavelength resonator. Those coupled structures result from different orientations of a pair of open-loop resonators, which are separated by a spacing S_{OLRR}. It is obvious that any coupling in those structures is in close proximity coupling, which is, basically, through fringe fields.

The nature and the extent of the fringe fields determine the nature and the strength of the coupling. It can be shown that at resonance of the fundamental mode, each of the open-loop ring resonators has the maximum electric field density at the side with an open gap (g_{OLRR}) and the maximum magnetic field density at the opposite side. Because the fringe field exhibits an exponentially decaying character outside the region, the electric fringe field is stronger near the side having the maximum electric field distribution, whereas, the magnetic fringe field is stronger near the side having the maximum magnetic field distribution. It follows that the electric coupling can be obtained if the open sides of two coupled resonators are proximately placed, as shown in Fig. 2.

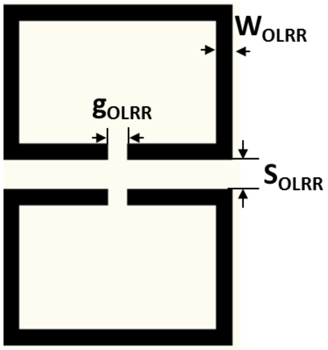


Fig. 2. Folded open-loop ring resonators.

To obtain the maximum magnetic coupling, the center valley of the OLRRs must be positioned in the proper location along the microstrip line with the maximum magnetic field intensity, which can be determined by studying wave motions on a microstrip line. For the Transverse Electromagnetic (TEM) field structure, it is assumed that both the electric and magnetic field vectors lie in the transverse plane perpendicular to the uniform propagation axis. Under the assumptions of the TEM mode of propagation and a lossless line, the fields are uniquely related to voltage and current, respectively. Based on transmission line theory, the magnitude of the voltage and current on the microstrip line can be expressed in terms of the incident wave and the reflection coefficient:

$$|V(z)| = |V_0^+| \left|1 + |\Gamma| e^{j(\theta - 2\beta l)}\right|, \tag{1}$$

$$|I(z)| = \frac{|V_0^+|}{Z_0} \left|1 - |\Gamma| e^{j(\theta - 2\beta l)}\right|, \tag{2}$$

where l=-z is measured away from the load at z=0, and θ is the phase of the reflection coefficient. When θ-2 βd has a magnitude of zero or any multiple of 2π radians, the quantities in (1) and (2) are at their maximum and minimum magnitudes, respectively. For the case of an open-circuited line, (1) and (2) respectively become:

$$|V(z)| = |V_0^+| \left|1 + e^{j(\theta - 2\beta l)}\right|, \tag{3}$$

$$|I(z)| = \frac{|V_0^+|}{Z_0} \left|1 - e^{j(\theta - 2\beta l)}\right|. \tag{4}$$

At a distance of a quarter wavelength from the receiving end, the voltage becomes zero while the current is maximal. If the line is half a wavelength long, the current distribution near the center of the transmission line is maximal. High magnetic coupling results from a high conduction current. Once the points of Imax are found, the points of Hmax can be easily determined. Figure 3 shows a uniform section of a transmission line of length L1/L2, where L1/L2 is about 0.5λ under operation frequencies of 2.4/5.2 GHz. Similarity, with an operation frequency of 5.2 GHz applied to L1, Imax or Hmax occurs at distances of 0.135λ and 0.385λ from the receiving end. These results suggest that the resonant frequencies of the designed diplexer can be adjusted by changing the layout dimension of the OLRRs.

To demonstrate the proposed structure, two bandpass filters are designed using OLRRs. To excite two passbands, two different pairs of guided half-wavelength OLRRs must be located between two transmission lines terminated at the open end. Each OLRR provides a path coupled signal energy from one microstrip to another at around resonance. At above and below resonance, most of the signal energy is reflected back and standing waves are said to exist on the line. The diplexer was simulated using the HFSS simulator with loss factors (conductor loss and dielectric loss) included in the simulated response. The coupling paths shown in Fig. 4 were generally chosen specifically for each resonant frequency.

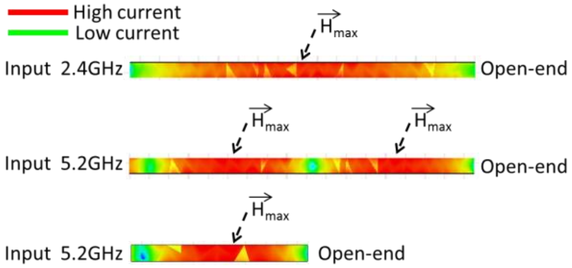
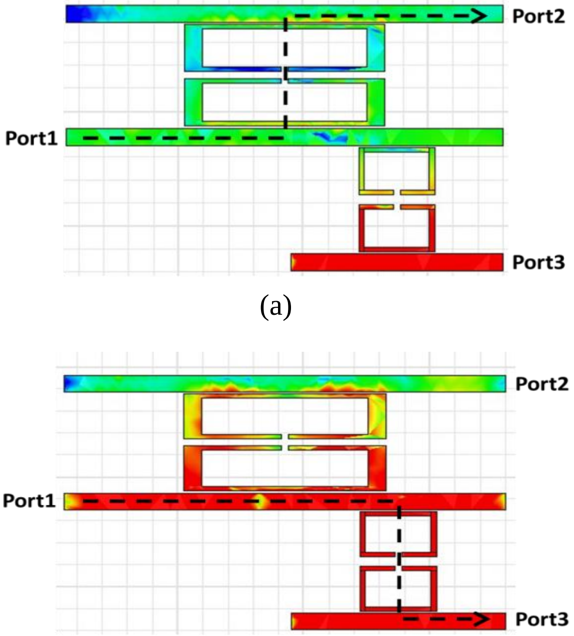


Fig. 3. Current distribution in microstrip line with an open end.



(a)

(b)

Fig. 4. Simulations of current distribution and coupling paths oscillating at: (a) 2.4 GHz, and (b) 5.2 GHz.

III. DESIGN OF DIPLEXER

The simulated frequency responses of 2.4-GHz and 5.2-GHz single-band filters are shown in

Fig. 5 with layout patterns shown in the inset. Each of the designed bandpass filters is based on a pair of half-wavelength OLRRs. Electric coupling can be obtained if the open sides of the two coupled resonators are placed near each other, and magnetic coupling can be obtained if the sides with the maximum magnetic field of two coupled resonators are placed near each other. The coupling spacing s between the main line and OLRRs is 0.2 mm and the spacing g1/g2 between two resonators is 0.61/0.81 mm. The simulation results of 2.4-GHz and 5.2-GHz filters are shown in Fig. 4. The center frequency of the designed filter can be accurately controlled to a desired frequency band once the right position is chosen. The simulation results of the designed diplexer show an adjustable frequency, good selectivity, high isolation, and a wide passband.

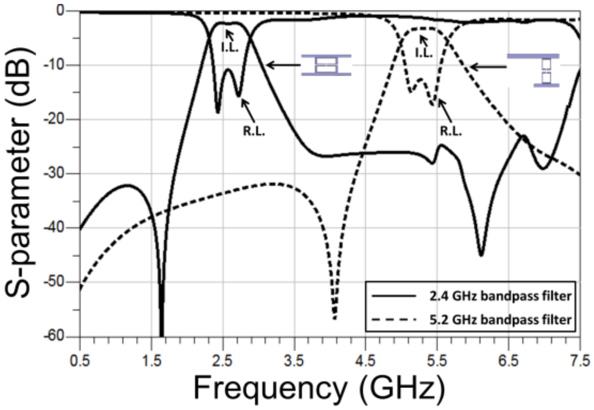
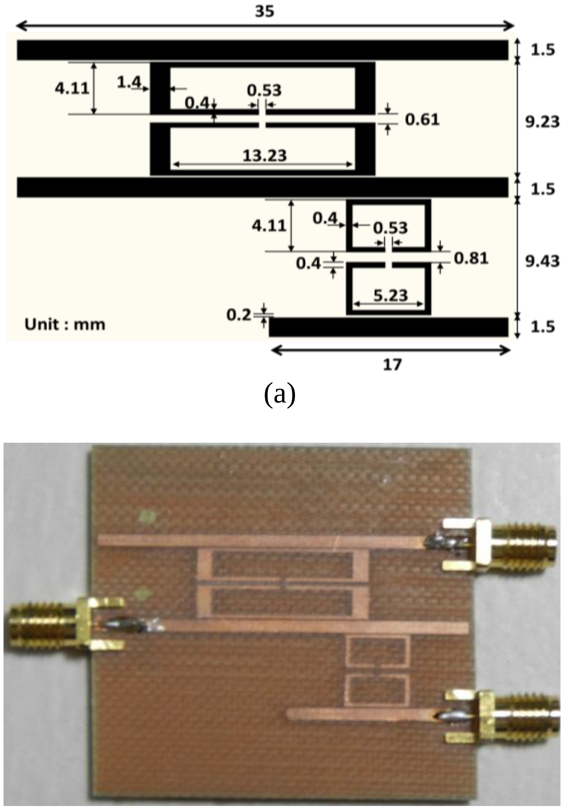


Fig. 5. Amplitude response of bandpass filters with center frequencies of 2.4 and 5.2 GHz.

The diplexer using OLRRs was fabricated on an FR4 substrate with a relative permittivity of 4.4 and a thickness between the two electrodes was 1.2 mm. The electrode's material was Cu foil with a thickness of 35 μm. The dimensions for the proposed diplexer are about 35×23.16 mm, as shown in Fig. 6 (a). A photograph of the designed 2.4/5.2-GHz diplexer is shown in Fig. 6 (b). Measurements were carried out using an Agilent N5071C network analyzer. The measured S-parameters of the fabricated diplexer are compared to the simulation results in Fig. 7. The measured responses show a reasonably good agreement with the simulated responses. The isolation between the two channels is larger than 25 dB. The lower and higher bands are located at 2.65 and 5.4 GHz with respective insertion losses of 1.94 and 2.55 dB, respectively. The measured return losses at lower and higher bands are less than -15 dB. Table 1 shows the comparisons of the superiority of the insertion loss (I.L.), circuit size, and bandwidth between the proposed diplexer and other literatures. As the table shows, the proposed diplexer had wider bandwidth and acceptable insertion loss, circuit size, and isolation.



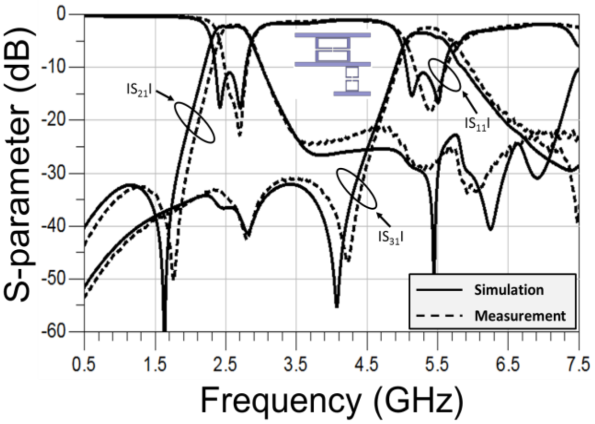
(a)

(b)

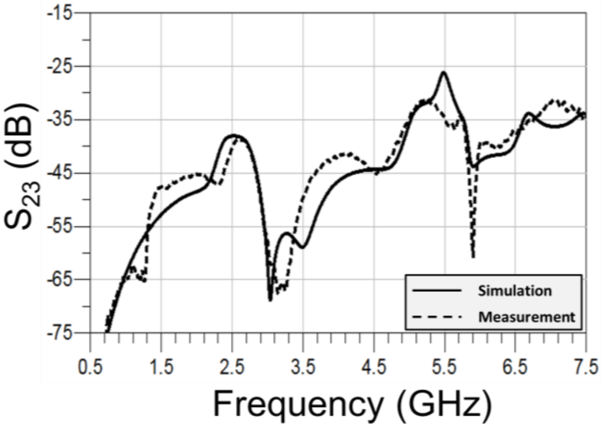
Fig. 6. (a) Layout pattern, and (b) photograph of designed 2.4/5.2-GHz diplexer.

Table 1: Results comparison between the proposed diplexer and the references [18,19]

	This work	Ref. 18	Ref. 19
Circuit Size (mm^2)	35x23.16	44x11	26x56
Passbands (GHz)	2.65/5.4	1.98/2.23	1.5/2/2.4/3.5
I.L. (dB)	1.94/2.55	1.8/3.01	0.8/1/0.7/1.5
FBW (%)	12.5/5.9	6.3/4.3	8/4/6/2
Isolation (dB)	>25	>40	>3



(a)



(b)

Fig. 7. (a) Measured and simulated S-parameters (S_{21}, S_{11}, and S_{31}), and (b) isolation (S_{23}) of diplexer. Diagram of the fabricated diplexer is shown in the inset.

IV. CONCLUSION

A simple and effective method based on standing waves and coupling for designing a microstrip diplexer was proposed. The electric and magnetic couplings between microstrip lines and two folded OLRRs are simultaneously provided to produce high-performance band-pass filters. By adjusting the physical dimensions of the OLRRs, the center frequencies of the diplexer can be tuned separately over a wide range. A 2.4/5.2-GHz diplexer was fabricated and measured to demonstrate the proposed structure. The rejection between the two passbands was lower than 25 dB and the insertion loss for each band was lower than 3 dB. The measurement results are in good agreement with the simulation results.

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