LETTER

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A microstrip dual-band bandpass filter using feed line with SIR

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Abstract: In this paper, a new design method of the dual-band bandpass filter which consists of feed line with stepped-impedance resonator (SIR) structure, open-loop ring resonator (OLRR) with SIR, and uniform OLRR is proposed. The SIR structure which can control harmonic frequencies is used to provide the maximum magnetic coupling at the same positions of both the upper and lower feed lines, irrespective of the first passband and the second passband of the dual-band bandpass filter and improve characteristic of stopband between the first and second passbands. This proposed design method was confirmed to be useful from measured results for dual-band bandpass filter operated at 2.4 GHz and 5.5 GHz.

Keywords: dual-band bandpass filter, magnetic coupling, open-loop ring resonator, stepped impedance resonator

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

As cellular phone and WLAN (Wireless Local Area Network) technology develop, various wireless communication services have been appeared. In order to provide multi-wireless services in a single wireless communication terminal, the necessity of multi-band RF front-end is a growing trend and various structures of multi-band bandpass filter (BPF) has been actively studied.

The structures in [1, 2] may adjust only the center frequency of each passband of dual-band BPF, but it is hard to adjust the bandwidth of each band to satisfy the design specification. The methods to adjust bandwidth of each band of dual-band BPF were proposed [3, 4]. But because signals pass the common path, the design procedure is complicated and the adjustment of bandwidth is limited. So the twin-filter method which can independently design each band was proposed [5, 6, 7]. This type of dual-band filter is obtained by combining two individual single-band filters via a common input/output port. Because signals of the two bands pass through different resonators, it is easy to realize two individual single-band filters to be designed independently.

The filter which is comprised of two uniform microstrip feed lines and two pairs of uniform open-loop ring resonators (OLRRs) was proposed by Chen [5]. The signal may be propagated well without external impedance-matching block by placing a pair of OLRRs at the position where the intensity of current distribution on feed line is maximal. However, open loads are diagonally placed in this structure, so the locations of maximum current distribution on one feed line do not always correspond to those on the other feed line. To overcome this problem, the length of feed line may be chosen to be the least common multiple of half wavelengths at the center frequencies of each passband, but the length is unnecessarily increased.

In this paper, the design method of the dual-band BPF which is modified by stepped-impedance resonator (SIR) structure, is proposed in order to overcome the above mentioned problems of the filter with uniform feed line. In order to confirm the proposed method the BPF with dual-band at 2.4 GHz and 5.5 GHz is designed and fabricated.

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Using the SIR structure provides the reduction of the length of dual-band BPF, the improvement of stopband characteristic, and the reduction of coupling between the first and second resonators.

2 Proposed filter structure

The proposed filter consists of feed lines with SIRs, a pair of uniform OLRRs (Res. 1 and 2) and a pair of OLRRs with SIRs (Res. 3 and 4), as shown in Fig. 1. All OLRRs must be located at the positions of maximum current distribution on feed lines to obtain maximum magnetic coupling between OLRR and feed line.

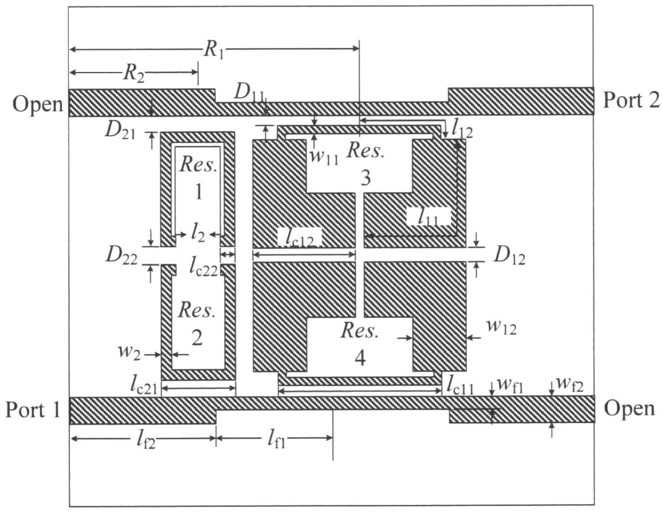

Fig. 1. Proposed dual-band bandpass filter structure.

The SIR structure can control the fundamental and spurious resonance frequencies by using the impedance ratio and the length ratio of a transmission line [8]. This SIR is applied to feed line and OLRR in this paper.

Firstly, the feed line with SIR may be designed to be a half wavelength long at the center frequency (f_1) of the first passband and one wavelength long at that (f_2) of the second passband. Then, the current distributions on the feed lines at two center frequencies are shown in Fig. 2. The maximum current densities on two feed lines are occurred at the same locations unlike [5]. In [5] which used the uniform feed lines, open loads are diagonally placed, so the locations of maximum current distribution on one feed line do not always correspond to those on the other feed line. So, the proposed configuration gives a maximum magnetic coupling between a resonator and a feed line at both the first passband and the second passband of the dual-band BPF. Therefore, one physical feed line with one open-end functionally operates as two electrical lines, so the filter can be miniaturized by reducing a superfluous length.

Secondly, SIR is used in OLRR for the first passband so that the second spurious frequency of OLRR may be forced to be appeared out of the second passband. If SIR is not used, the second spurious frequency would be in the stopband between the first and second passbands, and the stopband characteristics may be deteriorated. Consequently, the OLRR with SIR may improve the stopband

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characteristics. Also, the coupling between the first and second passband resonators may be reduced, and so the distance between the first and second passband resonators may be minimized.

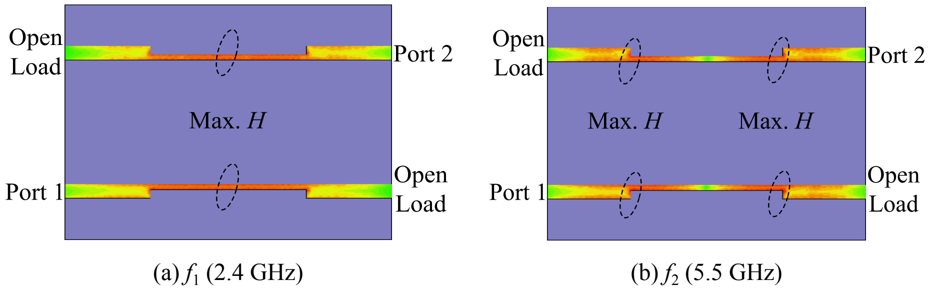

Fig. 2. Current distributions of feed lines with SIRs at f_1 and f_2.

3 Filter design

The dual-band BPF with Butterworth response was designed and fabricated to validate the proposed method. The specifications and the associated design parameters of the dual-band BPF are listed in Table I.

Table I. Specifications and design parameters

Parameters	Band 1	Band 2
Center frequency	2.4 GHz (f_1)	5.5 GHz (f_2)
3 dB-Bandwidth	400 MHz	700 MHz
(Fractional Bandwidth)	(16.7%)	(12.7%)
Order	2	2
Element values	$g_1 = g_2 = 1.4142$ $g_0 = g_3 = 1$	$g_1 = g_2 = 1.4142$ $g_0 = g_3 = 1$
Coupling Coefficient	$K_1 = 0.118$	$K_2 = 0.09$
Q-factor	$Q_1 = 8.48$	$Q_2 = 11.11$

The dual-band filter was designed on a RT/Duroid 6010LM substrate with a dielectric constant of 10.2, a thickness of 1.27 mm, and a loss tangent of 0.0023. The geometric schematics of feed line were determined firstly. From Table I, the frequency ratio, $a = f_2/f_1$, equals to 2.29, so $R_z = Z_2/Z_1$ and $U = \theta_2/(\theta_1 + \theta_2)$ are determined by 0.64 and 0.54, respectively and we can obtain $Z_1 = 78$ ohm ($w_{f1} = 0.4$ mm), $Z_2 = 50$ ohm ($w_{f2} = 1.0$ mm), $\theta_1 = 0.6$ rad ($l_{f1} = 3.9$ mm) and $\theta_2 = 0.7$ rad ($l_{f2} = 4.3$ mm).

Because the size of the second band resonator is smaller than the first band resonator, firstly we designed the second band resonator for the convenience of design. The second band OLRR is designed by using a uniform OLRR [9] which is a half wavelength resonator at f_2 ($l_2 = 10$ mm) and bended uniformly.

The coupling coefficient K_2 against line width (w_2), coupling gap (D_{22}) and coupling length (l_{c22}) was calculated at f_2 [10] by using full-wave simulator (Ansys HFSS). The desired coupling coefficient ($K_2 = 0.09$) may be obtained at

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$D_{22} = 0.52$ mm for $w_2 = 0.4$ mm and $l_{c22} = 0.9$ mm. The position of uniform OLRR (R_2) is 4.8 mm for maximum magnetic field coupling.

The quality factor Q_2 against coupling length (l_{c21}) and space (D_{21}) was calculated at f_2 and the bandwidth of uniform OLRR were defined by group delay and phase of S_{11} that were obtained by using Ansys HFSS [10]. The desired Q-factor ($Q_2 = 11.11$) may be obtained at $D_{21} = 0.36$ mm for $l_{c21} = 3.2$ mm.

Now the first band resonator of a OLRR with SIR structure was designed in the same way as the design procedure of a uniform OLRR. The difference is to move the second harmonic frequency of the first band resonator which could appear between the first band and second bands outside the second passband (7.0 GHz). Thus we can improve stopband characteristic and coupling with the second band resonator may be minimized.

R_z and U are 0.38 and 0.54, respectively for $a = 2.9$. And, $Z_1 = 80$ ohm ($w_{11} = 0.3$ mm), $Z_2 = 30$ ohm ($w_{12} = 2.6$ mm), $\theta_1 = 0.6$ rad ($l_{11} = 3.9$ mm) and $\theta_2 = 0.7$ rad ($l_{11} = 4.3$ mm) are obtained. The coupling length (l_{c12}) between resonators is 3.75 mm. The desired coupling coefficient, $K_1 = 0.118$, against space between two SIRs (D_{12}) may be obtained at $D_{12} = 0.44$ mm. The position of SIR (R_1) is 10.7 mm. The coupling length (l_{c11}) between feed line and SIR is 6.8 mm, and the desired Q-factor ($Q_1 = 8.48$) is obtained at $D_{11} = 0.36$ mm.

4 Simulated and measured results

Photograph of the fabricated dual-band BPF is shown in Fig. 3. The size of the filter including the feed lines is 19 mm × 9.2 mm. One filter is for the first passband, and consists of OLRRs with SIRs and feed lines with SIRs. The other which consists of uniform OLRRs and feed lines with SIRs is for the second passband. Fig. 4 shows the frequency responses of two filters, simulated by Ansys HFSS. The theoretical frequency responses of each single-band filter are also shown in Fig. 4 for comparison. The simulated results obtained without optimization are well agreed with the results of the theoretical filter response. From Fig. 5, the measured values and the simulated values are compared in Table II. The return loss in the stopband between the first band and the second band is less than −38 dB. Thus, in spite of the very close spacing between two resonators we can see that the coupling between two resonators is very weak.

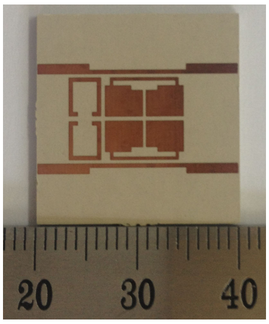

Fig. 3. The fabricated dual-band bandpass filter.

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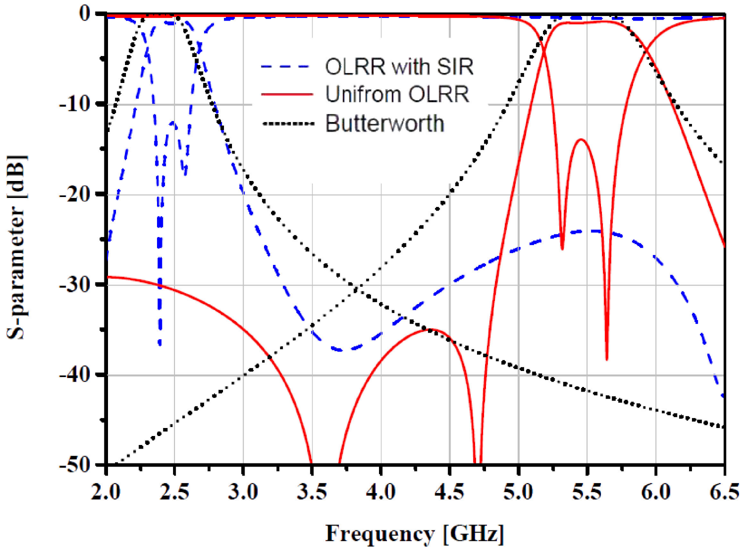

Fig. 4. Simulation results for individual single-band filters.

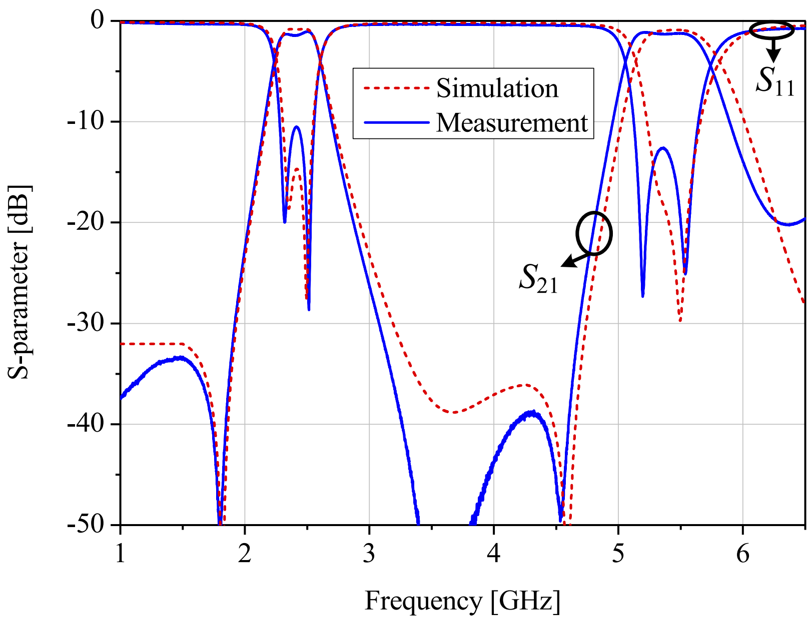

Fig. 5. Simulated and measured frequency responses for the proposed filter

Each BPF of the proposed dual-band filter structure is placed on the position of the maximum magnetic field on the common I/O port to provide the maximum coupling between each BPF and the common I/O port. So the coupling between each BPF and the common I/O port is strong, but the coupling between two independent BPFs which have different center frequencies are very weak. Thus the passband characteristics of each filter remains and corresponds to those of the complete filter.

The external quality factors obtained by design phase are compared in Table II. The external quality factor is a function of center frequency, insertion loss, and 3-dB bandwidth. There are little differences among the compared external quality factors. In the first passband the differences between the theoretical external quality

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Table II. Comparison between the measurement and the simulation

		Simulation	Measurement	Difference (%)
1st Band	Center frequency [GHz]	2.43	2.42	−0.01 (−0.4%)
	3 dB-bandwidth [MHz]	372	376	+4 (+1.1%)
	Insertion loss [dB]	0.8	1.0	+0.2 (4.7%)
	External Q	9.59	9.38	−0.21 (−2.2%)
2nd Band	Center frequency [GHz]	5.47	5.40	−0.07 (−1.3%)
	3 dB-bandwidth [MHz]	676	681	+5 (0.7%)
	Insertion loss [dB]	0.9	1.1	+0.2 (4.7%)
	External Q	11.57	11.20	−0.37 (−3.2%)

factor and others are relatively large. The reason is that the center frequency of the first passband was shifted a lot from the specification. However, the quality factors of the individual filters, the simulated complete filter, and the measured complete filter have little differences. That is, the characteristics of individual single-band filters are almost corresponded to those of the combined complete filter.

Thus, since the coupling between the first passband resonators and the second passband resonators is very weak, each individual passband can be designed independently using the traditional method.

5 Conclusion

The novel design method of dual-band bandpass filter which consists of feed lines with stepped-impedance resonator (SIR) structure, open-loop ring resonators (OLRRs) with SIRs, and uniform OLRRs is proposed.

Using the SIR structure the feed line is designed to be a half wavelength long at the center frequency of the first passband and one wavelength long at that of the second passband. The maximum current densities on two feed lines are occurred at the same locations unlike the previous other result, so the proposed configuration gives a maximum coupling between a resonator and a feed line. Therefore, the filter can be miniaturized by reducing a superfluous length.

If OLRR for the first passband is combined with SIR, then the second spurious frequency of OLRR may be forced to be appeared out of the second passband. So, the stopband characteristic between the first and second passbands may be improved, and also the coupling between the first and second passband resonators may be reduced, and so the distance between the first and second passband resonators may be minimized.

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