RESEARCH ARTICLE

Mixed-coupling multi-function quint-wideband asymmetric stepped impedance resonator filter

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Abstract

A new mixed-coupled quint-wideband ASIR bandpass filter with low insertion loss and compact size is proposed: spiral and open-loop coupled structures realize fundamental mode coupling and enhance another four spurious modes with optimum insertion loss. The fundamental frequency and four spurious frequencies are located at 1.275 GHz with fractional bandwidth (FBW) of 38.4%, 3.225 GHz with FBW of 38.4%, 5.875 GHz with FBW of 12.1%, 7.515 GHz with FBW of 13.7%, 9.74 GHz with FBW of 4.3%. The filter is suitable for multiple applications including GPS, Wi-Fi and IEEE 802.11a, and partially for IEEE 802.16. The quint-wideband filter has a performance superior to its currently proposed quint-wideband counterparts.

KEYWORDS

BPF, microstrip filter, quint-wideband, stepped impedance resonator

1 | INTRODUCTION

The microstrip bandpass filter (BPF) is one of the fundamental components in microwave communication systems. Bandpass filters with good characteristics, such as low insertion loss, multi-function, wide passband, and compact size, are required in communication systems.^{1–7} With the current increasingly stringent demands on frequency resources, multi-band filters with multiple functions covering various communication standards and applications are highly in demand, and accordingly many multi-band filters designs have been presented.^{3–5} Among them, tri-band bandpass filters and quad-band filters are strong candidates. However, these two types of filter have narrow-band characteristics which cannot cover the sufficient frequency bands, unsatisfactory insertion loss performance, or are relatively large in size. To improve filter performances and address the problems mentioned above, the quint-band filter was first proposed in 2012,³ with tri-mode stub-load stepped-impedance resonators to realize quint-band performance. A multiple-stub loaded ring resonator (MSLRR) is proposed in⁴ using directly coupled multi-band bandpass filters (BPFs) with mixed electric and magnetic coupling (MEMC). In Reference 5 it is proposed to utilize three pairs of simple microstrip stepped-impedance resonators on the top and middle metal layer, and two pairs of slot uniform-impedance resonators on the bottom metal layer. Quint-band performance can indeed be realized by these individual structures, but all of these filters have relatively complicated structures such as multiple via holes,^{3,4} multi-layer structure,⁵ etc. These disadvantages complicate the design and fabrication, leading to high loss and cost.

In this article, a compact quint-wideband bandpass filter with low insertion loss, wide passband, and compact size is proposed, which dispenses with complex structures. The filter is designed, fabricated, and measured. Good agreement between simulated and measured results is obtained. Furthermore, it is significant that this design can be easily developed to handle and permit reconfigurability^{6,7} and can be easily integrated with antenna design,⁸ to create the so-called “filtenna”.⁹ The filter design and its performance are presented and discussed in the next coming sections.

2 | PROPOSED CIRCUIT MODEL AND ANALYSIS

Figure 1 shows the proposed second-pole mixed coupled stepped impedance resonator (ASIR) filter. In the ASIR structure, each resonator has a high and low-characteristic impedance section. Its resonances occur when $Y_{in} = 0$ in Equation 1.

$$Y_{in} = \frac{j}{Z_2} \frac{k \tan \theta_1 + \tan \theta_2}{1 - k \tan \theta_1 \tan \theta_2} \quad (1)$$

In the proposed design, two low characteristic impedance sections are folded to reduce the patch size, and high-characteristic impedance sections are partially coupled with each other to form the spiral and open-loop structure leading to mixed electric and magnetic coupling. The electric coupling is generated between the gaps of the coupled high impedance sections, since the SIR has the maximum electric fringe field density at the open ends.¹⁰ The magnetic coupling is achieved by the parallel coupled section. According to [2], S_{21} can be calculated as:

$$S_{21} = -2j \frac{2j \text{Im}(y_{12})}{1 - \text{Im}(y_{11})^2 + \text{Im}(y_{12})^2 + 2j \text{Im}(y_{11})} \quad (2)$$

The transmission zeros occur when $S_{21} = 0$. The Y-parameters y_{ij} ($i, j = 1, 2$) are related elements with coupling length L_{cp} . Therefore, by adjusting L_{cp} , the transmission zeros can be relocated. This facilitates forming the multi-pass band, in conjunction with the mixed electric and magnetic coupling effect.

The center and both ends of an ASIR coupled section are where the magnetic and electric fields in the fundamental mode peak respectively. To enhance the electric coupling of the filter, the ends of two adjacent spiral ASIRs can be closely located, which can be adjusted by g_1 . We can enhance the magnetic coupling of the fundamental mode by closely positioning the parallel coupling parts of two adjacent spiral ASIRs, which can be achieved using g_2 .¹¹ The field peak field points of the proposed filter are shown in Figure 2. The coupling points of spurious modes can be

FIGURE 1 The proposed quint-wideband mixed-coupling ASIR filter with the description of electric and magnetic coupling effects [Color figure can be viewed at [wileyonlinelibrary.com](#)]

FIGURE 2 Peak field points of the filter using spiral and open-loop couple structure [Color figure can be viewed at [wileyonlinelibrary.com](#)]

adjusted by changing coupling length L_{cp} . The spurious modes can also be adjusted by changing uncoupled section lengths L_{u1} and L_c , which gives added freedom in designing the multi-band filter. The effect of the spiral and open-loop coupled high characteristic impedance line structure (SOLHLS) in ASIRs is reflected in the surface current distribution at the fundamental frequency and the other spurious frequencies, as illustrated in Figure 3. Magnetic coupling is important in determining the fundamental frequency because the electrical coupling is weakened by the long distance between two open ends, whereas the four spurious modes, f_{s1} , f_{s3} , f_{s4} , and f_{s5} , have current densities are distributed in different places of the SOLHLS, which means the SOLHLS facilitates the forming of high-order modes in the proposed quint-band filter.

3 | FILTER DESIGN AND RESULTS

To investigate the character of the proposed structure, the filter is simulated by HFSS and fabricated on a Rogers RO3210 substrate with dielectric parameter of 10.2, $\tan \delta$ of 0.0027 and thickness of 0.635 mm. The dimensions of the spiral and open-loop ASIR filter in Figure 1 are $L_{u1} = 5.9$ mm,

FIGURE 3 The quint-wideband spiral and open-loop coupled ASIR BPF surface current distribution at (A) f_0 , (B) f_{s1} , (C) f_{s3} , (D) f_{s4} , and (E) f_{s5} [Color figure can be viewed at [wileyonlinelibrary.com](#)]

FIGURE 4 Simulated, measured results and photograph of the proposed quint-wideband ASIR filter and its performance comparison [Color figure can be viewed at wileyonlinelibrary.com]

$L_{u2} = 6.6$ mm, $L_c = 9.3$ mm, $L_{cp} = 17.8$ mm, $g_1 = 0.22$ mm, $g_2 = 0.2$ mm, and $W_1 = 1.6$ mm. The total size of the proposed cross-coupled spiral SIR filter is $0.11 \lambda_g \times 0.34 \lambda_g$, where λ_g is the microstrip guided wavelength at f_0 . Its measured result agrees well with the simulation. Figure 4 shows simulated and measured results of the quint-wideband ASIR filter with SOLHLs, and a comparison to the simulation of performance without the SOLHLs structure. Figure 4 also shows a photograph of the fabricated circuit. Good agreement is observed between the simulated and measured results:

TABLE 1 Performance comparison with currently quint-band BPFs

	CF(GHz)/3 dB FBW (%)	Insertion loss (dB)	Size	Extra structure
3	0.6/5.8%	2.8	$0.045\lambda_g \times 0.52\lambda_g$	Via hole
	0.9/5.2%	2.9		
	1.2/5.8%	2.9		
	1.5/8.2%	2.6		
	1.8/8.0%	2.3		
4	0.63/28.8%	0.47	$0.043\lambda_g \times 0.178\lambda_g$	Via hole
	1.33/9.4%	1.14		
	2.03/2.7%	1.8		
	2.74/5.3%	1.39		
	3.45/5.5%	1.26		
5	1.5/4.5%	1.5	$0.24\lambda_g \times 0.17\lambda_g$	Multi-layer
	2.5/4.5%	1.8		
	3.5/3.6%	0.9		
	4.5/4.5%	1.2		
	5.8/2.7%	2.5		
This work	1.275/38.4%	0.41	$0.11\lambda_g \times 0.34\lambda_g$	None
	3.225/12.1%	1.27		
	5.875/12.1%	0.83		
	7.515/13.7%	1.74		
	9.74/4.3%	1.55		

discrepancies can be attributed to losses and fabrication errors. The first pass band ranges from 1.03 to 1.52 GHz with central frequency (CF) of 1.275 GHz, bandwidth (BW) of 490 MHz: this is suitable for GPS applications (L1 band: 1.57542 GHz, L2 band: 1.22760 GHz, L3 band: 1.38105 GHz, and L4 band: 1.84140 GHz). The second pass band ranges from 3.03 to 3.42 GHz with CF of 3.225 GHz, BW of 390 MHz, which can be used in 3G Wi-Fi and partly WiMAX for 802.16 (3.3–3.7 GHz) application. The third pass band ranges from 5.52 to 6.23 GHz with CF of 5.875 GHz, large BW of 710 MHz. It can be used in IEEE 802.11a applications. The fourth pass band ranges from 7.00 to 8.03 GHz with CF of 7.515 GHz, large BW of 1.03 GHz, while the fifth pass band ranges from 9.53 to 9.95 GHz with CF of 9.74 GHz, BW of 420 MHz. They can be used in satellite communications. Two transmission zeros located at 2.49 GHz and 4.98 GHz, which are also illustrated in Figure 4, further enhance the frequency selectivity. The performance of this proposed quint-wideband ASIR filter in comparison with other quint-band BPFs is shown in Table 1.

4 | CONCLUSIONS

A novel mixed-coupled quint-wideband ASIR bandpass filter which uses spiral and open-loop coupled structure to realize fundamental mode coupling and enhance another four spurious modes coupling with optimum insertion loss performance has been proposed in this letter. The proposed filter has the advantages of applicable quint-wideband, large fractional bandwidth, simple structure and compact size, making it attractive for future versatile microwave/RF applications in multi-function wireless communications.

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