A Miniaturized Microstrip Dual-Band Bandpass Filter using Folded UIR for Multimode WLANs

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Abstract ─ A novel microstrip dual-band bandpass filter (BPF) using folded half-wavelength uniform impedance resonator (UIR) with high selectivity is presented. The proposed filter with two tuneable passbands has advantages such as compact size and simple structure. The passband frequencies have been adjusted for 2.4 GHz and 5.2 GHz wireless local area networks (WLANs). The overall size is reduced by 30 % in comparison with the two section radial stepped impedance resonator (SIR). The measured insertion loss is less than 0.18 dB and 0.5 dB in the first and second passbands, respectively. Also the measured return loss is more than 30 dB and 20.73 dB in the first and second passbands, respectively. There is a good agreement between the measured and the simulated results.

Index Terms ─ Bandpass filter, stepped impedance resonator, and uniform impedance resonator.

I. INTRODUCTION

In recent years, dual-band BPFs are widely used for microwave and wireless systems such as global system for mobile communication (GSM) and (WLAN). The center frequency of the second passband of the conventional half-wavelength UIR is two times of the fundamental frequency, so it seriously suffers from unwanted harmonics and has a large size. To solve this problem, the use of non-uniform line resonators such as two section SIRs is considered [1]. So an SIR exhibits advantages in the size reduction and good harmonics suppression as compared to a UIR. The filter in [1] with three SIRs has a minimum insertion loss of 2dB in the fundamental passband. In [2], a highly selective dual-band BPF is presented using radial SIR and input-output T-shaped lines with minimum insertion loss of 1.6 dB, 2.2 dB, and 3 dB bandwidth of 2.5 % and 2.2 % in two passbands. In [3], two dual-bands BPF are presented using resonator-embedded cross-coupled structure for GSM (900/1800 MHz) with minimum insertion loss of 3 dB and 4 dB and WLAN (2.4/5.2 GHz) with minimum insertion loss of 2 dB and 2.5 dB in its passbands. In [4], a BPF using a three section SIR with the minimum insertion loss of 2.5 dB at the fundamental frequency is presented. In [5], a compact BPF to suppress spurious harmonics with minimum insertion loss of 1.75 dB and 3 dB bandwidth of 1.8 % at the fundamental frequency (2.22 GHz) is presented using the UIR and three sections SIR.

In all these structures, the length reduction of the SIRs results in the increment of the width, which finally increases the filter size. Also due to cascaded structures [1, 4] and weak coupling between the resonators [2, 3, 5], their insertion losses in the passbands are not good.

In [6], a BPF using folded hairpin octagonal double hairpin-shaped resonators with side coupled structure has achieved compact size due to the slow-wave performance and self-capacitance. But its minimum insertion loss is 2 dB at the fundamental frequency. The stopband

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with the attenuation level of -20 dB is only from DC to 900 MHz and from 940 MHz-1200 MHz. The dual-band BPF in [7] is composed of folded open loop half-wavelength resonators and stepped impedance structures. This filter has a small size, but it has high insertion losses. In [8], pseudo-interdigital SIRs are used to design the BPF with dual-band response. This filter has a large size and high insertion losses. In [9], a dual-band BPF using SIRs is designed. This filter has good harmonics attenuation, but it has large size and high insertion losses. In [10], a triple band BPF using hairpin SIRs is presented. This filter has the advantage of having triple band, but it suffers from having a very large size. Also it has high insertion losses in three passbands in spite of cascaded structure.

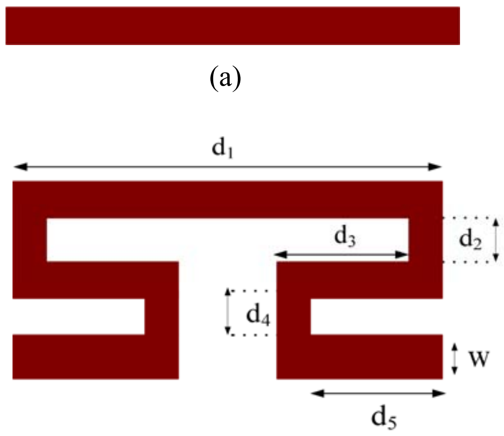
In [11, 12], two SIR BPFs using defected ground structure (DGS) are presented. Although, these filters have improved rejection bands, their insertion losses in the passbands are not so good, and their total dimensions by considering two layers are large. Also in the DGS structure, it has not been a robust mechanical endurance against strain due to etching in the ground plane.

In this paper, a new miniaturized dual-band BPF with low insertion loss and high selectivity using folded half-wavelength UIR is presented. The conventional half-wavelength UIR has been folded to eliminate spurious harmonics. By tuning the spaces between the stubs, the second band frequency can be adjusted. Moreover, the modified UIR results in an overall size reduction as compared to the SIR, due to the slow-wave effect.

II. BANDPASS FILTER DESIGN

The conventional half-wavelength UIR is shown in Fig. 1 (a), which is folded to achieve a capacitive loading between the arms and also to minimize the length. This can be shown in Fig. 1 (b) with a good slow-wave performance.

The LC equivalent circuit of the proposed resonator is shown in Fig. 2, where L_a, L_b, L_c, L_d, and L_e represent the inductances of the stubs d_1, d_2, d_3, d_4, and d_5, respectively. Furthermore, C_{g1} is the capacitance of the gap between the stub d_3 and d_5. The capacitances C_{g2} and C_{g3} represent the gap between the centred folded stubs. The capacitance C_p is that of the stub d_5 with respect to the ground.



(a)

(b)

Fig. 1. A schematic view of the (a) conventional UIR and (b) the proposed folded UIR.

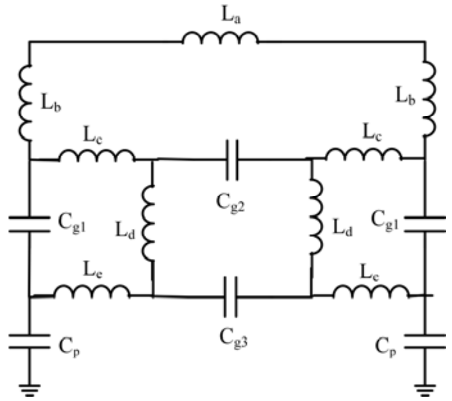


Fig. 2. LC equivalent circuit of the proposed resonator.

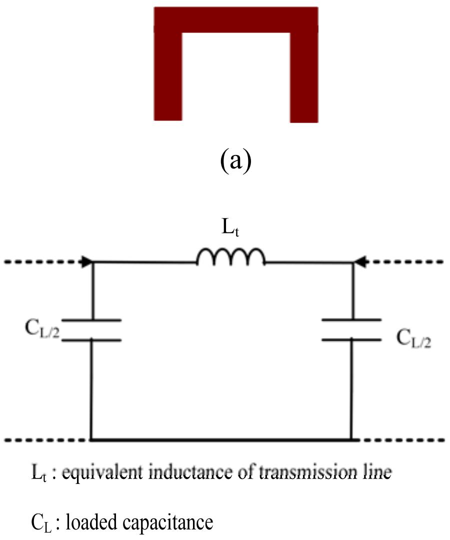
A capacitive loaded lossless transmission line resonator is shown in Fig. 3 (a) and its LC equivalent circuit is shown in Fig. 3 (b), where the proportion of the first spurious resonant frequency to the fundamental frequency as shown in [13] is,

$$\frac{f_2}{f_1} = 2\frac{v_{p2}}{v_{p1}} \qquad (1)$$

where v_{p1} and v_{p2} are the phase velocities of the loaded line at the fundamental and the first spurious resonant frequencies, respectively. The dispersion equation as shown in [13] is given by,

$$\cos(\beta d) = \cos\theta_a - \frac{1}{2}\omega C_L Z_a \sin\theta_a \qquad (2)$$

where C_L, Z_a, β, d and, θ_a are the loaded capacitance, characteristic impedance, the propagation constant, the length of the unloaded line, and the electrical length, respectively.



(a)

(b)

Fig. 3. (a) Capacitively loaded transmission line resonator structure and (b) the LC equivalent circuit of the structure.

By plotting the dispersion curves based on equation (1), it can be shown that the dispersion effect results in the increment of the ratio of the first spurious resonant frequency to the first fundamental [13]. Therefore, this property can be used to design a bandpass filter with a wider upper stopband. Thus, the LC equivalent circuit of the proposed resonator consists of more self-capacitances than the resonator in [13]. This is in order to improve the slow-wave performance.

The electrical length (θ) of a conventional half-wavelength UIR is defined as shown in [14] by equation (3) as follows,

$$\theta = \beta l \qquad (l = \pi) \tag{3}$$

where

$$\beta = 2\pi / \lambda_g \,, \tag{4}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\,h/W\right)^{-0.5} , \tag{5}$$

$$\lambda_g = \frac{300}{f(GHz)\sqrt{\varepsilon_{re}}}(mm) , \tag{6}$$

where β, l, λ_g , ε_{re}, f, ε_r, W, and h are the propagation constant, physical length, guided wavelength, effective dielectric constant, fundamental frequency, relative dielectric constant, and the width and thickness, respectively. The fundamental frequency is adjusted by the proper physical length at 2.4 GHz, so by changing the total length of the resonator ($d_1 + 2d_2 + 2d_3 + 2d_4 + 2d_5$), the fundamental frequency changes. In the conventional half-wavelength UIR, the spurious frequencies resonate at $f = nf_1$ (n = 2, 3, …). On the other hand, the proposed structure exhibits variations of gaps between the stubs i.e., d_2 and d_4, which results in changing the spurious frequencies, especially the gap d_4 is an effective parameter in controlling the spurious frequencies of the filter.

The S- parameter simulation of the proposed resonator as a function of d_4 is shown in Fig. 4. The decrement of the gap d4, which results in the increment of the capacitive loading, increases the second band frequency. Therefore, the proportion of the centre frequency of the second passband to the fundamental frequency (f_2/f_1) gets bigger.

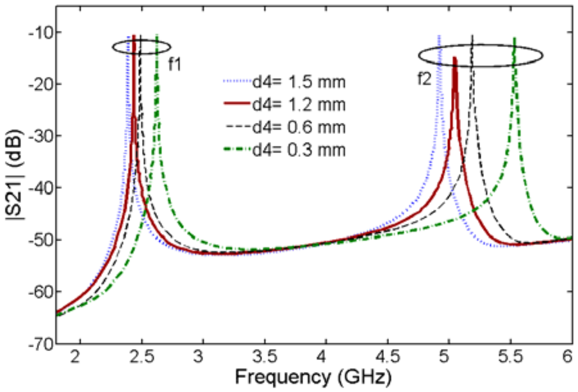


Fig. 4. Simulated insertion loss of the new resonator with varying d_4.

The proposed filter is shown in Fig. 5, where d_4 = 1.2 mm results in f_2/f_1 = 2.16. The T-shaped coupling lines are used to realize parallel coupling to the folded UIRs and also create two finite transmission zeros. The dual-band BPF is designed for two passbands, located at 2.4 GHz and 5.2 GHz. The dimensions of the filter are shown in Fig. 5.

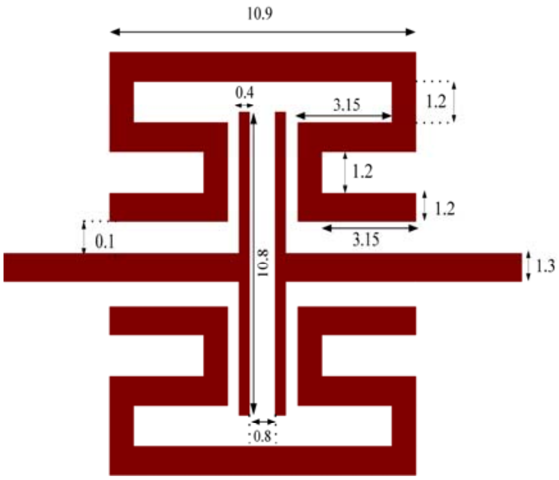
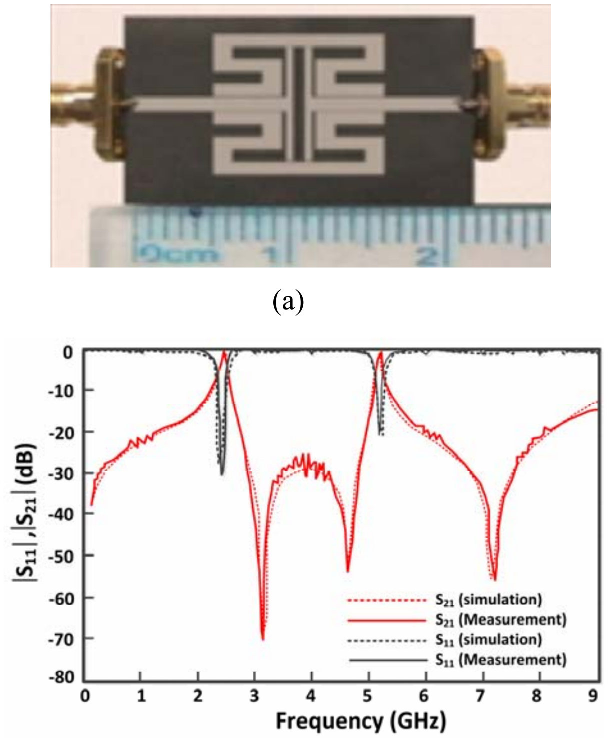


Fig. 5. The layout of the designed filter (unit: in mm).

III. SIMULATED AND MEASURED RESULTS

The photograph of the fabricated filter is shown in Fig. 6 (a). The BPF is fabricated on a substrate with relative dielectric constant of 6.15, thickness of 31 mil and loss tangent equals to 0.0009. The filter is simulated by the method of moments in ADS software. HP8757A network analyzer is used for measurements. The simulated and the measured results are in good agreement as can be shown in Fig. 6 (b).

The measured centre frequencies of the two passbands are located at 2.4 GHz and 5.2 GHz. The measured insertion loss has an improvement of 780 % and 340 % in comparison to the two section radial SIR. Also the measured return loss has an improvement of 36 % and 5 %, in comparison to the two section radial SIR. The 3 dB bandwidth of 3% and 1.3 % is obtained for the two passbands. The return loss in the stopband region is very close to 0 dB, indicating negligibly small radiation loss. The filter size is 10.9 mm × 13.5 mm (0.2 λg × 0.24 λg). A comparison of the designed filter with previous works is shown in Table 1, where IL_1, IL_2, f_1, and f_2 corresponds to the insertion loss in the first passband, insertion loss in second passband, first passband, and the second passband, respectively. It is observed that, the proposed filter has a small size and good performance.



(a)

(b)

Fig. 6. (a) The photograph of the fabricated filter and (b) the simulated and measured results of the proposed filter.

Table 1: Comparison between the proposed filter and previous works.

Ref.	Resonator Type	IL_1 (dB)	IL_2 (dB)	f_1 (GHz)	f_2 (GHz)	Size (mm^2)
[2]	two section radial SIR	1.6	2.2	2.45	5.2	209.4
[3]	miniaturized hairpin resonator and stepped impedance hairpin resonator	1.2	2.3	2.4	5.2	850.3
[7]	folded open loop half-wavelength resonators and SIR	0.6	1	2.45	5.7	168.5
[8]	pseudo-interdigital SIRs	0.8	1.2	2.4	5.2	192.9
[9]	SIRs	2.12	2.33	2.45	5.8	1905
Filter	**Folded UIR**	**0.18**	**0.5**	**2.4**	**5.2**	**147.1**

IV. CONCLUSION

In this paper, a miniaturized dual-band BPF using folded half-wavelength UIR with high selectivity is presented for WLAN signals, which has been designed, fabricated, and measured. The proposed resonator has a significant improvement for the insertion loss and the return loss in its passbands. Moreoevr, a favorable size reduction has been achieved.

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