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Tuning the Resonance Frequency and Miniaturization of a Novel Microstrip Bandpass Filter

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Abstract: In this paper, a compact microstrip bandpass filter is designed using two open loop resonators. In order to obtain a tunable bandpass response with low insertion loss, two stubs are loaded inside them. The design process is based on obtaining the input admittance. Then, using the input admittance, a method is presented to control the resonance frequency and miniaturization simultaneously. The obtained insertion loss and the return loss at the resonance frequency are 0.1 dB and 19.7 dB respectively. To verify the design method, the proposed filter is fabricated and measured. The measured results are in good agreement with the simulated results.

Keywords: Microstrip filter; Tunable; Miniaturization; Insertion loss.

نطاق ترددي مضغوط باستخدام شريحة جديدة متناهية الصغير

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الملخص: في هذه الورقة البحثية، تم تصميم مرشح نطاق ترددي مضغوط باستخدام رناناتين ذواتا حلقة مفتوحة . و من أجل الحصول على استجابة نطاق قابل للضباط ذو بخسارة منخفضة عند الإدراج ، يتم تحميل شريحتين بداخله .وتعتمد عملية التصميم على معرفة حاصل الإدخال .ولاستخدام مدخل الادراج ، قمنا بتقديم طريقة للتحكم في تردد الرنين والتصغير في نفس الوقت .وتبلغ نسبة الخسارة في الإدراج التي تم الحصول عليها والخسارة عند رجوع تردد الرنين: ا،. دي بي و ١٩،٧ دي بي على التوالي .وللتحقق من طريقة التصميم ، يتم تصنيع الفلتر المقترح وقياسه .و اظهرت نتائج القياس توافقا بشكل جيد مع نتائج المحاكة.

الكلمات المفتاحية: مرشح ، شريحة متناهية الصغر، قابل للانضباط ،التصغير ، الخسارة في الإدراج

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1. Introduction

High performance and compact microstrip filters play an important role in developing modern microwave/RF communication circuits and systems. To design microstrip filters several types of resonators such as: open loops (Hayati *et. al*. 2012; Salehi *et. al*. 2014; Hayati *et. al*. 2014; Zhang *et. al*. 2012), parallel-coupled lines (Moradian *et. al*. 2009; Othman *et. al*. 2013; Fathelbab *et. al*. 2005; Kuan *et. al*. 2010) and quarter/half wavelength resonators (Li *et. al*. 2010; Deng *et. al*. 2010) have been used. Also, several approaches on suppressing harmonics have been proposed (Kang *et. al*. 2010; Wang *et. al*. 2008; Chen *et. al*. 2009; Cheng *et. al*. 2014; Wu *et. al*. 2017). In Zhang *et. al*. (2012), three open loop resonators are used to design a bandpass filter with a high selectivity. However, it has an undesired fractional bandwidth. The common weakness of these reported filters is their large sizes and large insertion losses. In Moradian *et. al*. (2009) a third-order bandpass filter is proposed to attenuate the harmonics. In Kuan *et. al*. (2010), the parallel coupled lines and step impedance resonators are used to design a microstrip bandpass filter. A microstrip bandpass filter operating at 1.78 GHz with suppressed harmonics up to 6.2 GHz is presented in Li *et. al*. (2010). But this filter has a large return loss. In Kang *et. al*. (2010), a ring-balun bandpass filter has been proposed to attenuate the harmonics up to 12 GHz. In Wang *et. al*. (2008), coupled ring resonators have been utilized to design a bandpass filter with a complex structure, while using a complex structure leads to hard fabrication. In Chen *et. al*. (2009), various types of bandpass filters have been introduced utilizing cross coupled resonators to suppress the second harmonic. Nevertheless, their stop bands are narrow. In Cheng *et. al*. (2014), the inductive-coupled stepped-impedance quarter-wavelength resonators are used to design a microstrip bandpass filter with an undesired insertion loss. A dual-mode microstrip bandpass filter operating at 1.67 GHz has been introduced in Lu *et. al*. (2017), which has a narrow fractional bandwidth and large area. A microstrip bandpass filter with high return loss has been designed in Guan *et. al*. (2017). In this filter, a triangular cell has been coupled to the step impedance feed structures that results in improving the bandwidth.

In this paper, first a simple resonator (open loop) is chosen similar to Hayati *et. al*. (2012); Salehi *et. al*. (2014); and Hayati *et. al*. (2014). Then, a method is proposed for miniaturizing and tuning the resonance frequency simultaneously. Using this method, the shapes and dimensions of the internal stubs can be determined as well as the resonance frequency. Next, a simple tunable bandpass filter is presented using two proposed resonators to solve the problems of previous works in terms of large implementation area and large insertion loss. In addition, the harmonics are attenuated reasonably and fractional bandwidth and selectivity are improved. Finally, the effect of changing the dimensions on the frequency response is investigated.

2. Filter Design

An open loop resonator is shown in Fig. 1a. A large size simple step impedance cell is loaded inside the proposed resonator to control the resonance frequency. The electrical lengths θ_i are used to obtain the input admittance, where $i=1, 2, 3, s$. An *LC* equivalent circuit of the proposed resonator is shown in Fig. 1b, where *C* and *L* are the capacitors and inductors of the bends respectively. The parameters C_g and C_p present the gap capacitors. The parameters of L_a, L_b, L_c, L_e, L_f and L_g are the inductors of the stubs with the physical lengths l_a, l_b, l_c, l_e, l_f, and l_g respectively. C_o is the capacitor of the open end, which its position is subsequent the loaded step. C_s, L_{S1} and L_{S2} are the capacitance and inductance of the step impedance cell. The input admittance from the open end of θ_1 can be written as follows:

$$Y_{in} = jY\frac{tan(\theta_1)+tan(\theta_2)+tan(\theta_3)+tan(\theta_s)}{1-tan(\theta_1)[tan(\theta_2)+tan(\theta_3)+tan(\theta_s)]} \quad (1)$$

where θ_s is the total electrical length of the step impedance cell, *Y* is the admittance of the step impedance cell and open loop resonator. For the even mode, when, $Y_{in}=0$, the resonance condition is obtained from:

$$tan(\theta_1)+tan(\theta_2)+tan(\theta_3)+tan(\theta_s)=0 \quad (2)$$

So the resonance condition can be tuned by adjusting θ_1, θ_2, and θ_3 while θ_s is fixed. The electrical length has a direct relation with the physical length. Therefore, the resonance frequency can be controlled by adjusting the loop and step impedance open stub dimensions.

When the electrical length θ_s is maximum, then from $\theta_s = l_s\,\beta$ (where β is propagation constant) l_s must be maximum. Therefore, by choosing a maximum value for l_s, (from Equation 2 and also from $\theta_s = l_s\,\beta$) $\tan(\theta_s)$ is increased and the total of $tan(\theta_1)+tan(\theta_2)+tan(\theta_3)$ is decreased ($tan(\theta_1)+tan(\theta_2)+tan(\theta_3)$ is minimum). Under this condition θ_1, θ_2, and θ_3 are small values. Therefore, (from $\theta_3=(l_a+l_g+l_f)\beta$, $\theta_2=l_c\beta$ and $\theta_1=l_e\beta$) the open loop dimensions consisting of l_a, l_b, l_c, l_e, l_f, *and* l_g are decreased. This is a method to decrease the resonator size and adjust the resonance frequency simultaneously.

As a total result of above discussion, a method to control the resonance frequency and miniaturization is obtained by the following steps: In the first step, a resonator is selected which some stubs are loaded inside it. In the second step, the main resonator size is decreased and the dimensions of stubs are increased, so that the desired resonance frequency can be obtained. In the proposed resonator (Fig. 1a), the physical lengths l_a, l_b, l_c, l_e, l_g and l_f must be smaller while the internal stub length must be larger. Therefore, the inductors L_a, L_b, L_c, L_e, L_g and L_f can be smaller and L_{S2} or/and L_{S1} can be larger.

According to Equation (2), in some cases, there is a degree of freedom to control the resonance frequency so that we have to use the optimization method. Therefore, in order to obtain a compact size at the target resonance frequency, the additional optimization is performed.

In order to design a bandpass filter as shown in Fig. 2a, two open loop resonators consisting of different step impedance cells are used. The loops are connected together using mix coupling. The coupling structure consists of three coupled lines with different widths, which are used to attenuate the harmonics. The feed structures with the step impedance forms are added to the input and output ports to decrease the insertion loss without size increment. The simulated and measured frequency responses of the propose filter are shown in Fig. 2b. According to the above discussion, the resonance frequency can be controlled by adjusting the physical lengths of open loops while the internal stubs have a maximum size. Therefore, a method to control the resonance frequency is changing of the lengths (L_3, L_9) or/and (L_4 , L_{11}).

The frequency response as a function of L_3, L_9, L_4 and L_{11} are shown in Fig. 3a and Fig. 3b. Figures 3a and 3b depict the loop size changing effect on the resonance frequency. When the loops are large, the resonance frequency is shifted to the left. When the loops are small, the resonance frequency moves to the right. A photograph of the fabricated filter is shown in Fig. 3c.

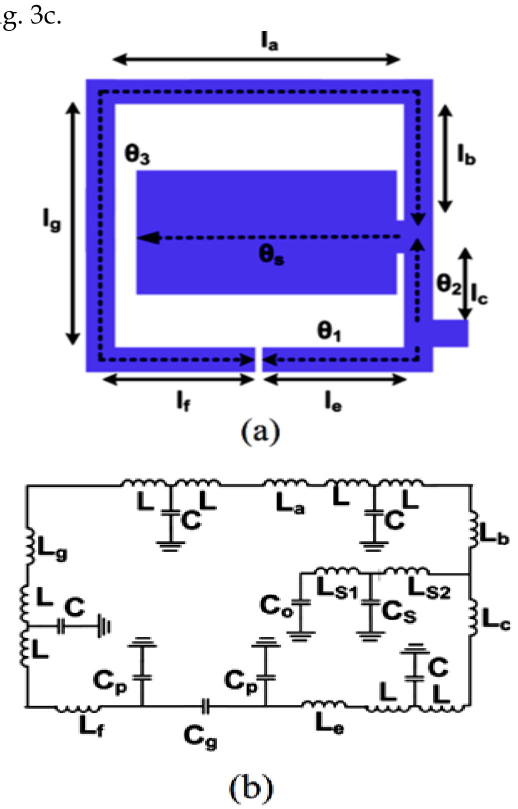

Figure 1. Proposed resonator (a) layout, (b) LC equivalent circuit.

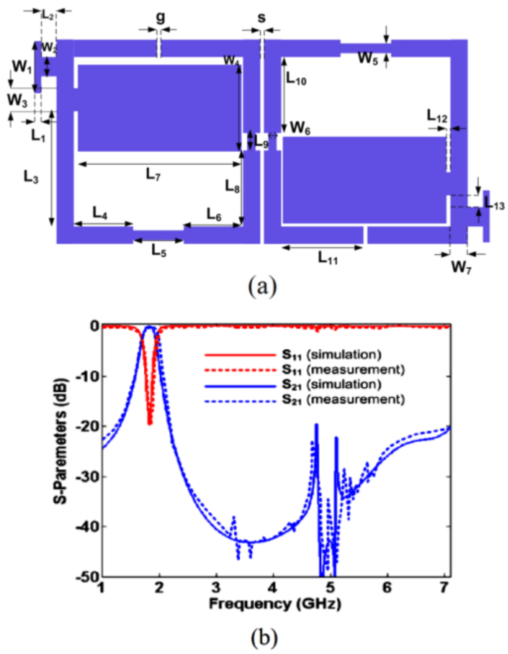

Figure 2. Proposed filter (a) layout, (b) frequency response.

3. Results

The proposed filter is simulated by Advanced Design System (ADS) full wave EM simulator. The proposed filter is designed and fabricated on a RT_Duroid_5880 substrate with 15 mil-dielectric thickness, ε_r=2.22 and loss tangent 0.0009. The dimensions of the proposed structure shown in Fig. 2a are presented in Table 1. This filter has the cutoff frequencies at 1.68GHz, 1.93GHz and the resonance frequency is 1.8GHz. The harmonics are attenuated from 2.16 up to 7.1GHz with a maximum level of -19.5dB. Therefore, the harmonics are attenuated up to 3.94f_o where f_o is the resonance frequency. The obtained insertion loss at 1.8GHz is better than 0.1dB, while the return loss is better than 19.7dB. The filter size is $0.23\lambda_g \times 0.1\lambda_g$ (26.7×12mm^2). In comparison to the previous works, the filter size is small and the best insertion loss is obtained. The achieved fractional bandwidth (FBW) is 14%. The insertion loss, return loss, fractional bandwidth, and filter size are compared to the previous works in Table 2. In the Table 2, IL, RL, and FBW are the insertion loss, return loss, and fractional bandwidth respectively.

4. Conclusion

A simple compact low loss bandpass filter is designed, fabricated and measured for RF systems. In this structure, two open loop resonators are loaded by two large stubs. By using the additional large size microstrip cells inside the open loops, the resonance frequency is decreased without size increment. The overall size of the proposed filter is 320mm^2. In comparison to all of the references, the lowest

Table 1. The dimensions of proposed structure (in mm).

Parameters	**L_1**	**L_2**	**L_3**	**L_4**	**L_5**	**L_6**	**L_7**	**L_8**
Value	0.3	1	6.8	3.5	3	3.5	9.7	4.5
Parameters	L_9	L_{10}	L_{11}	L_{12}	L_{13}	W_1	W_2	W_3
Value	1	4.5	4.8	0.2	1	3	1.2	1
Parameters	W_4	W_5	W_6	W_7	S	g		
Value	5	0.6	0.5	1	0.1	0.4		

Table 2. Comparison between the proposed filter and previous works.

Reference	**IL (dB)**	**RL (dB)**	**FBW**	**Size (mm^2)**	**f_o(GHz)**
This work	0.1	19.7	14%	320	1.8
(Hayati et. al. 2012)	0.53, 0.59	10, 13.4	---	320	2.4, 5.2
(Salehi et. al. 2014)	0.35 , 0.25	13.6, 18.2	17%, 13%	363	2.4, 5.7
(Hayati et. al. 2014)	0.2, 0.4	15, 12.7	13%, 11%	233	2.4, 5.2
(Zhang et. al. 2012)	2.2	---	6%	11595	0.95
(Moradian et.al. 2009)	3.85	---	13%	9000	1
(Kuan et.al. 2010)	2.5	15	12%	2034	2
(Li et.al. 2010)	1. 8	12	16.5%	488	1.78
(Deng et.al. 2010)	1.66	---	9.5%	606	2.41
(Kang et.al. 2010)	1.34	21.6	4.08%	1564	2.45
(Chen et.al. 2009)	0.83	---	11.2	2300	2
(Cheng et.al. 2014)	0.85	---	11.5%	220	2.35

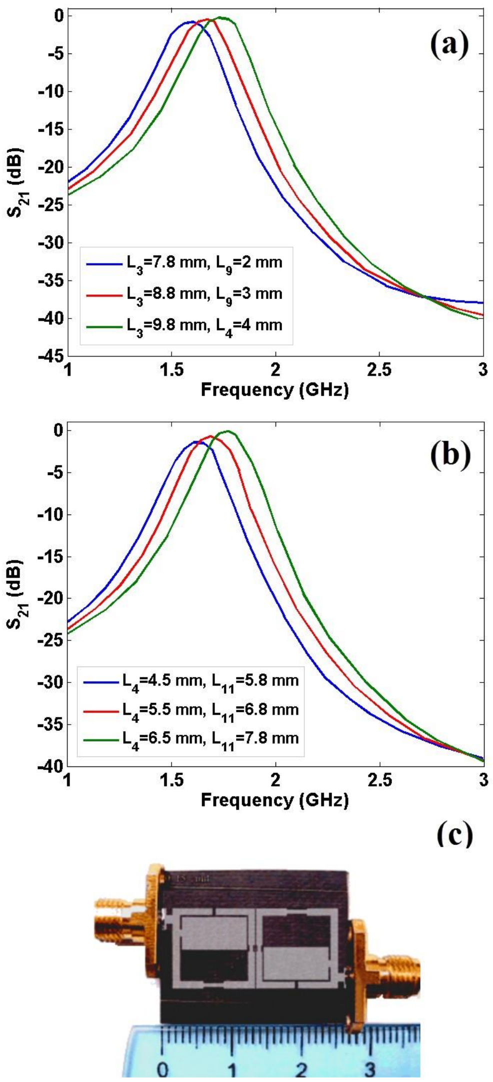

Figure 3. (a) Frequency response as a function of L_3 and L_9, (b) Frequency response as a function of L_4 and L_{11} , (c) a photograph of the fabricated filter.

insertion loss is obtained, while the harmonics are attenuated from 2.16 to 7.1GHz with a maximum attenuation level of -19.5dB. In addition, the resonance frequency is tuned by calculation of the input admittance

Conflict of Interest

The authors declare no conflicts of interest.

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