Design, Simulation and Implementation of Very Compact Dual-band Microstrip Bandpass Filter for 4G and 5G Applications

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***Abstract*—This article proposes a very compact planer open-loop bandpass filter (BPF) with asymmetric frequency response and covering the 2.5 to 2.6 GHz and 3.6 to 3.7 GHz spectrum for 4G and 5G applications, respectively. The microstrip BPF employs four open-loop ring resonators with 50 Ω tapped lines for input and output ports. To achieve sharper cut-off frequencies, one infinite and three finite transmission zeros are successfully generated on the upper and lower edges of the 4G and 5G passbands. The utilization of the planer four-section resonators not only reduces the size of the structure, but also provides either positive or negative cross-coupling. The cross-coupling coefficients between the resonators are optimized to resonate at the required frequency with proper bandwidth. The reported BPF is designed and optimized using CST software, and is implemented on a Rogers RO3010 substrate with a relative dielectric constant of 10.2 and a very compact size of 11×9×1.27 mm^3. Good agreement is achieved between the simulated and measured results.**

Keywords—microstrip filter, bandpass, open-loop, 4G, 5G applications, compact, CST.

I. Introduction

RF noise is a serious concern in recent applications of wireless communications such as green communications and wide-band radar systems [1]. Planer bandpass filter is commonly employed to suppress noise and undesirable signals in different communication systems [2], basically in RF and microwave communications because of their effective rejection of harmonic signals. Currently, 5G application technologies are being utilized for use in 700 MHz, 3.6 GHz and 26 GHz spectrums [3]. BPFs must fulfill specific requirements in 5G applications [4]. A BPF consists of a number of coupled elements and resonators, and the sizes of the distributed lines describes the filter specifications and performance. In addition, most planer design miniaturization techniques try to reduce these factors.

Different designs and methodologies have been presented for planer microwave filters such as combline, hairpin, parallel-coupled line, step impedance, and stub impedance [5-15]. A planer structure with Chebyshev characteristics is presented for a 2.44 GHz mid-band frequency with 0.55 dB ripple factor. The obtained insertion loss is less than 1.1 dB and return loss is greater than 13 dB [6]. In [8], a small size microstrip BPF was proposed by using a novel transmission coupled line method. Two microstrip transmission lines of three parallel-coupled sections, a quarter wavelength long, was utilized to build a band-pass filter with a mid-band frequency of 2.8 GHz. Non-Uniform elements are used to separate the two transmission lines, and the size of the structure was 20.5×7.5 mm^2. Another technique in [9] used low temperature co-fired ceramic (LTCC) structure, whose fabrication is realized by utilizing the reliable electromagnetic investigation, resulting in proper filter designs with a very compact size. Microstrip hairpin structures can be employed to design a compact size band-pass planer filters. The analysis of these structures eployes a variable coupling across the hairpin resonators with T-feeders [10]. For this design, the measurement results of mid-band resonant frequency is shifted down by roughly about 0.3 GHz compared with the simulation results. The resonant frequency is 5.7 GHz necessary for RFID wireless communications. The size of the proposed band-pass filter is about 26×12 mm^2. From the other side, Combline band-pass filter structures, with the merit of compact size and low loss, are usually prefered in today wireless communications [11, 12]. In [11], a novel implemented Combline BPF is proposed with two transmission zeros, two poles, and physical dimensions of 27.4×5.5 mm^2. The operation frequency for the reported filter is 1.45 GHz with a -3 dB fractional bandwidth (FBW) of about 12 %, insertion loss 2.8 dB and passband return loss 18.5 dB. An improved combline BPF with an array of stepped-impedance (SIRs) is proposed and implimented in [12]. The filter has the advantage of few via-hole grounds which is recommended by multilayer planer structures. Same design can be modified with 4th order BPF and will have a return loss and the insertion loss greater than 16 dB and less than 1.8 dB respectively, all by using a microstrip structure with physical dimensions 12.5×10 mm^2.

From the other side, some wireless communication systems of microstrip filters demand a high selectivity on only one edge of the passband, but less or none on the other edge. Therefore, employing a design with asymmetric frequency response will be required [2]. This is due to the fact that a symmetric frequency characteristics designs will lead to a high number of resonators, high insertion loss, larger size and a high cost circuits.

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This article presents a very compact 4-pole microstrip open-loop ring resonator BPF with asymmetric frequency response, simulated using CST software tool to operate with the frequency bands of 3.5 to 3.6 and 3.6 to 3.7 GHz, and suitable for 4G and 5G communications, respectively. The proposed four-section band-pass design is implemented on a Rogers RO3010 substrate with a relative dielectric constant of 10.2 and a very compact size of 11×9×1.27 mm^3. In addition, it is worthy to say that this design can be easily modified to tackle and gain tenability properties [16] and could be easily combined with antenna structure [17], to accomplish the so-called "filtenna" [18]. The proposed open-loop microstrip BPF and its simulation and measurement results are analyzed and explained in the following sections.

II. 3-POLE SINGLE-BAND BPF

The design steps of the reported BPF can be summarized with the following procedure:
Step 1) Design a low-pass filter (LPF) prototype with normalized characteristics impedance (g0) and cut-off frequency (Ωc).
Step 2) Using some transformation techniques to convert thedesigned low-pass filter prototype to the band-bass filter operating on the required resonant frequency. This step will resulting in a band-pass filter with a lumped-elements circuit consists of a capacitors and inductors.
Step 3) Richards' transformation can be applied to transform the band-pass filter into a microstrip planer band-pass filter [2].

A. Low-Pass Filter (LPF) Prototype

A 3-pole lumped element LPF prototype is presented on this step. The filter is resonating on 3.6 GHz with FBW 11% and low ripple factor. The equivalent circuit of the prototype filter with order n is shown in Fig. 1 with LPF prototype parameters g_i for i=0 to n+1. According to [2], The LPF with Butterworth characteristics can be employed to compute the values of g_i to give: $g_0 = g_4 = 1$ ℧, $g_1 = g_3 = 1$ H and $g_2 = 2$ F for cut-off frequency $\Omega_c = 1$ rad/s.

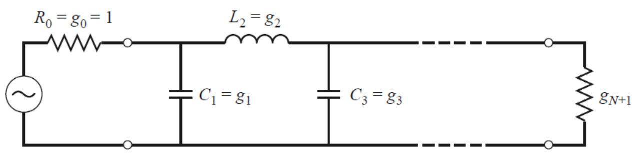

Fig. 1. A ladder circuit of the prototype LPF.

B. Design of Lumped Element Circuit of the BPF

Frequency and element transformation techniques can be applied to obtain the lumped-element circuit of the BPF from the designed LPF prototype (which has a normalized characteristic impedance $g_0 = 1$ and $\Omega_c = 1.0$ rad/s). The angular frequency conversion affects just the reactive elements and has no effect on the resistive elements. The angular cut-off frequency and the impedance scaling factor are $2\pi \times 3.6 \times 10^9$ rad/s and $\gamma_0 = 50$ respectively. From [2], we find $L_1 = L_3 = 22$ nH, $L_2 = 0.15$ nH, $C_1 = C_3 = 0.1$ pF and $C_2 = 18$ pF. As a result, and according to the procedure detailed above, we can get the equivalent circuit of the lumped-element BPF as shown in Fig. 2. The S_{11} and S_{21} results of this filter are shown in Fig. 3.

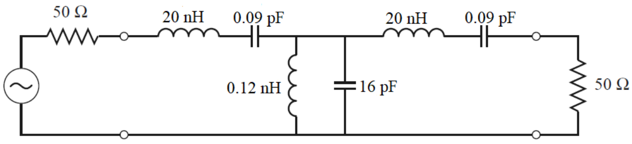

Fig. 2. Equivalent circuit of the lumped-element BPF.

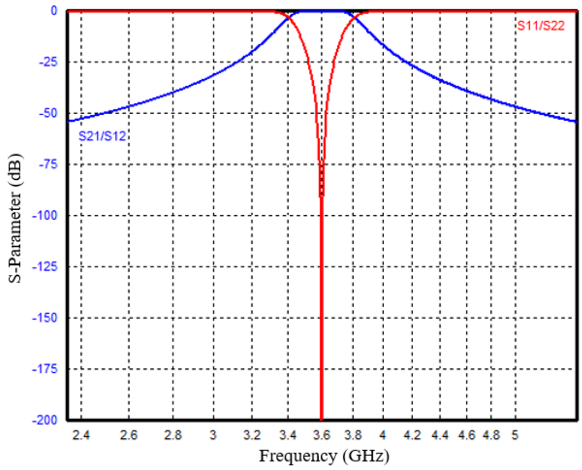

Fig. 3. S_{21} and S_{11} of the designed lumped-element BPF.

C. Design of the 3-pole Open-loop Microstrip BPF

According to [2], Richards' transformations [2] are applied to convert the designed lumped-element BPF designed into a transmission line model.

The geometry of the proposed cross-coupled BPF is shown in Fig. 4. Three open-loop ring-resonators fed by two ports 50 Ω input impedance minimize the physical size, eliminating the need for vias. The filter has a transmission line feed and uses Rogers RO3010 substrate, with h = 1.27 mm, $\varepsilon_r = 10.2$ and loss tangent = 0.0022. The resonant frequency 3.6 GHz is chosen as it is suitable for 5G.

The equivalent circuit of the trisection open-loop BPF can be performed as shown in Fig. 5. M_{12} and M_{23} denote the coupling coefficients between the adjacent resonators, and the cross coupling coefficient between the resonators 1 and 3 is represented by M_{13}. The external quality factors for the input and output couplings are represented by Q_{ei} and Q_{eo}, respectively. The angular frequency of resonator n is $\omega_{0n} = 2\pi f_{0n} = 1/\sqrt{(L_n C_n)}$ for n = 1, 2 and 3. To simplify the design, we can consider that M_{12}=M_{23}, Q_{e1}= Q_{e3} and $\omega_{01} = \omega_{03}$. For the proposed filter, it can be seen the cross coupling between resonators 1 and 3 is positive (M_{13}>0), and this denotes that the attenuation pole of finite frequency is on the upper edge of the pass-band. The physical parameters of the planer 3-pole filter can be calculated by employing the same design steps detailed in [19]. The configuration of the BPF filter and its optimized parameters are shown in Fig. 4 and Table 1, respectively. In addition, the dimensions of the proposed BPF is about 0.27 λ_{g0} × 0.17 λ_{g0}, where λ_{g0} represents the guided wavelength of a 50 Ω transmission line on the substrate at the resonant frequency 3.6GHz.

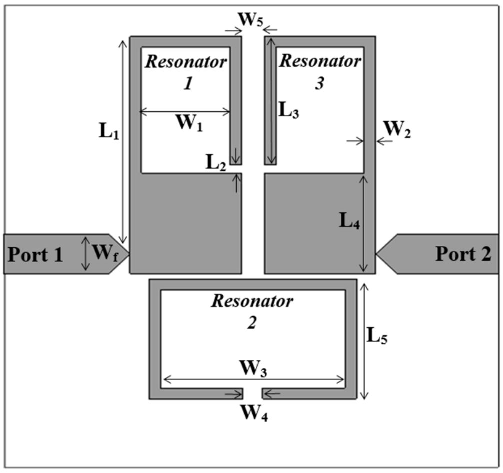

Fig. 4. Layout of the designed 3-pole BPF.

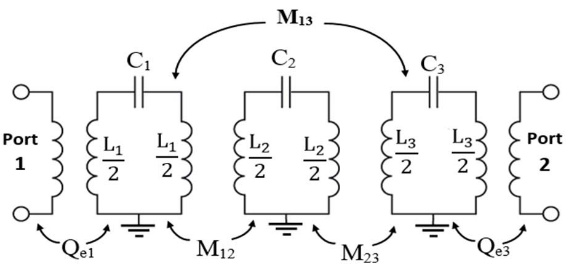

Fig. 5. Equivalent circuit of the 3-pole microstrip BPF.

Table 1. The optimized parameters of the designed cross-coupled microstrip BPF.

Parameter	Value (mm)
L_1	6
L_2	0.24
L_3	3.29
L_4	2.83
L_5	3.3
L_6	2.9
L_7	0.3
W_1	2.3
W_2	0.3
W_3	4.8
W_4	0.51
W_5	0.6
W_6	0.9
W_7	9
W_f	1.1

Fig. 6 shows the simulated results of the return loss and the insertion loss of the designed 3-pole BPF. The simulation results show that the proposed filter has insertion loss of 0.8 dB across the pass-band with return loss better than 30 dB. Moreover, and to increase the selectivity of the pass-band, two transmission zeros have been successfully generated in the upper edge of the pass-band.

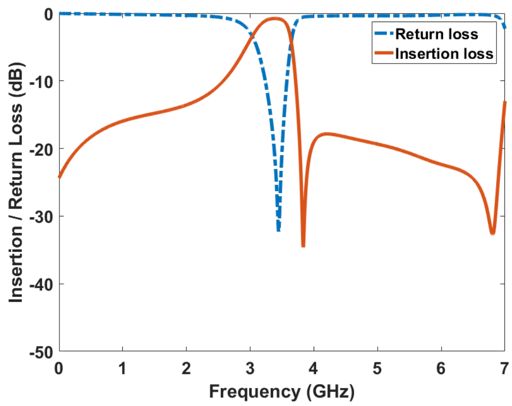

Fig. 6. S-parameter performance for the 3-pole BPF.

III. 4-POLE DUAL-BAND MICROSTRIP BPF

To achieve dual-band characteristics, resonator 4 is added to the 3-pole BPF. The length of the resonator is selected to be $\lambda_{g0}/2$, where λ_{g0} here represents the guided wavelength at the resonant frequency 2.5GHz. Fig. 7 shows the configuration of the designed 4-pole dual-band BPF, the geometry of the resonator 4 and photograph of the hardware realization of the proposed filter. Obviously, the size of the designed filter is very compact. The optimized parameters are obtained by using the trust region framework algorithm embedded with the CST software as detailed in Table 1. The simulated and measured s-parameter results are shown in Fig. 8. The achieved -10dB bandwidth is 100MHz for both 4G and 5G passbands with insertion losses are 0.9dB and 1.1dB, respectively.

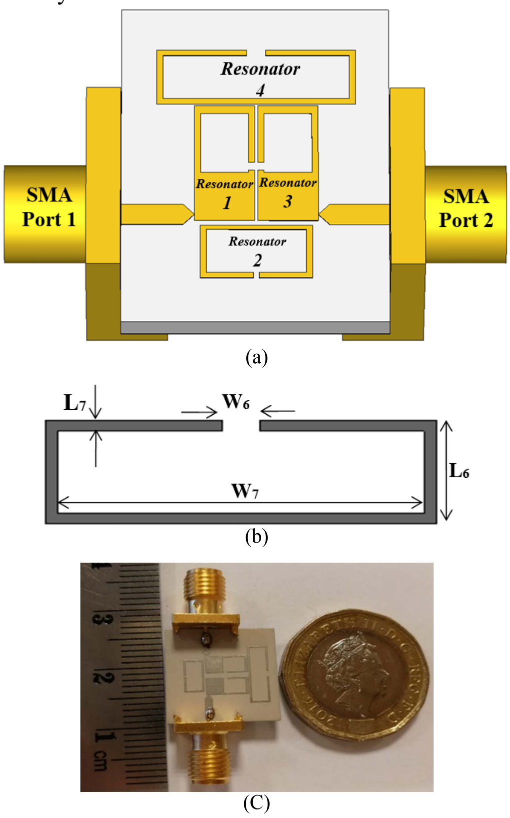

Fig. 7. (a) Layout of the designed 4-pole BPF (b) Configuration of the resonator 4 (c) Prototype photo of the fabricated 4-pole BPF.

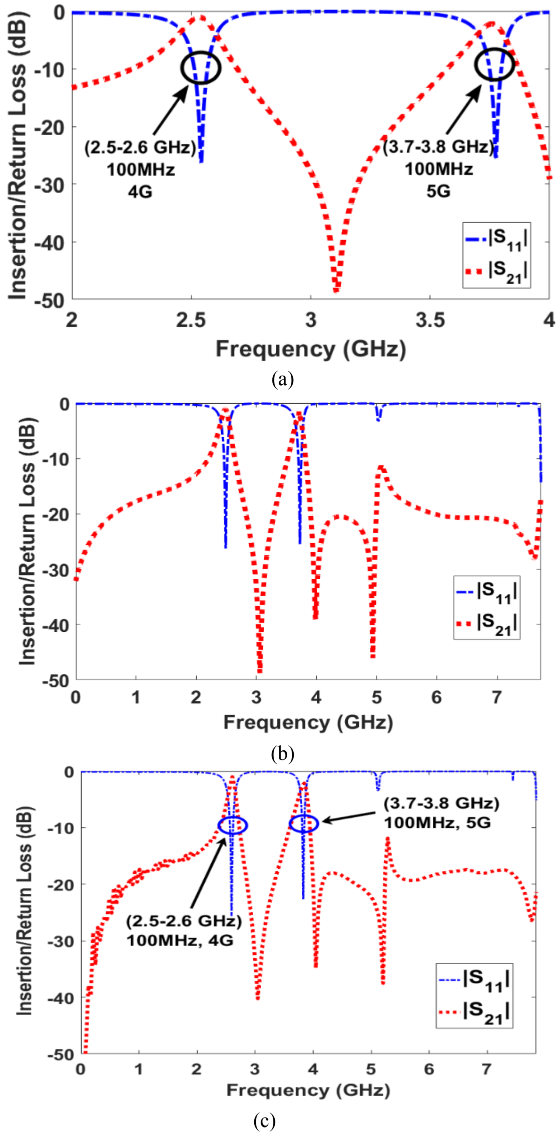

Fig. 8. (a) Frequency response for the 4-pole BPF. (b) Simulated wide-band frequency response. (c) Measured wide-band frequency response.

The proposed 4-pole cross-coupled band pass filter has a number of attractive properties, which include: (1) The proposed design is very compact in size and simply structured. (2) Good stopband rejection and selectivity have achieved. (3) The measured insertion loss is very low with good return loss and group delay to cover the 4G (2.5-2.6 GHz) and 5G (3.7-3.8GHz) spectrum. (4) Compared to the designed filters in [6], [8], [10] and [20], the proposed filter has smaller size and better performance with the merit of dual-band characteristics.

IV. CONCLUSION

A design for a very compact 4-pole microstrip bandpass filter is presented and implemented in this paper with asymmetric frequency response and covering 2.5 to 2.6 GHz and 3.4 to 3.7 GHz spectrum for 4G and 5G applications, respectively. Three finite transmission zeroes are successfully generated on the upper edge of the passbands to increase the selectivity of the proposed BPF. The measured results are in good agreement with simulated results.

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