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Four Cells Microstrip Bandstop Filter with open Loop Resonators and Thin Film Capacitors

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***Abstract*— This paper presents a quad-band microstrip bandstop filter based on open loop resonators having thin film chip capacitors. For this purpose, properties of open loop resonators are used and four independently controllable resonance frequencies are obtained by four open loop resonators in different electrical length. In order to obtain higher degree, four unit cells including four resonators are used. While center frequencies can be independently controlled, the same is not true for the bandwidths and rejection levels. The proposed filter was also fabricated for the experimental verification of the predicted results. Four stopbands at 1.5, 2.5, 5 and6.8 GHz were obtained in a good agreement with the predicted results.**

***Index Terms*— Bandstop filter, chip capacitor, microstrip, quad-band.**

I. INTRODUCTION

Microstrip filters play an important role in multiband microwave filter design because of their great advantages in terms of low loss, low cost, miniaturization and fabrication simplicity. Significance of multiband microwave filters are gradually increasing depending on the rapid developments in wireless communication systems including GSM, WLAN, WiMAX technologies, etc. There are several methods commonly used for multiband bandpass/bandstop microwave filter design such as using multi-mode resonators, stub loaded resonators, stepped-impedance resonators, multilayer structures, multiple resonators [1]–[7]. On the other hand, there are a few multiband bandstop filter design in the literature as compared to multiband bandpass filters. Also, although there are many dual and triple band bandstop filter studies, the number of quad-band bandstop filter design studies is limited according to the best of our knowledge [5]–[7]. In [5], a compact quad-band bandstop filter has been designed by means of open loop resonators and defected ground structure with high return losses especially in the third and fourth stopbands. Another quad-band bandstop filter design has been achieved by using open-circuited stubs in [7], however the stopbands cannot be controlled independently.

However, most of these filter configurations have relatively large dimensions that are unsuitable for compact systems. An alternative approach to designing compact filters is to use dual-mode resonators. Recently, a class of dual-mode complementary resonators has been introduced in [8] and [9] for sensing and filtering. Particularly, compact bandpass filters have been realized by loading such resonators on a microstrip line with series capacitive gaps. The advantages of these complementary structures are their compact size and high-*Q* resonance. Furthermore, they can be used for suppression of the unwanted harmonic responses [10]. These advantages make them preferable candidates for designing high-order compact filters with improved out-of-band responses.

In the last few years, several examples of tune-all microwave filtering devices with multipassband-type transfer function have been proposed. Among them, some exponents to be highlighted are those based on channelized-filter-bank/double multiplexer arrangements and multiband quasi-bandpass filtering sections with/without cross couplings [11]–[13]. Nevertheless, much less attention has been dedicated to their BSF counterparts. In relation to it, only a reduced number of discretely and continuously reconfigurable multiband BSFs have been reported. They have been developed in a variety of technologies that are based on lumped-element, hybrid lumped-element-acoustic-wave, planar, and evanescent-mode substrate- integrated- cavity resonators [14]–[18]. In the case of planar realizations, such as those presented in [14] and [17], they have shown some operational constraints, for example, the lack of bandwidth reconfiguration as well as control of the number of active stopbands, their limited upper passband bandwidth, and the lack of independent center-frequency reconfiguration in the filter prototype in [14]. In addition, they have been experimentally verified only in dual-stopband circuits. Moreover, due to practical aspects involved in their circuit structures, such as the use of multilayer geometries in [15] and [16] and RF transformers in [17], their real extrapolation to more-than-two-band implementations for a single stage can be more complicated than in the filtering architectures that are presented in this paper.

In this paper, a novel quad-band bandstop filter design is presented by using open loop resonators having two lumped capacitors located at the center of the coupled arm and between the open ends of the open loop resonators. Firstly, a unit cell is constructed by coupling the proposed resonator to a feedline used to connect Input/Output (I/O) ports. The unit cell is also analyzed based on the coupled line theory as expressed in [2]. Thus, it is observed that the even and odd mode resonance frequencies of the proposed resonator can be independently controlled by changing the capacitances of two lumped capacitors. Four independently controllable resonance frequencies can be obtained by using another open loop resonator at the bottom of the feedline in a different electrical length. Then, a quad-band microstrip bandstop filter design is achieved by introducing second unit cell with identical resonators. The designed filter has independently controllable four stopbands in terms of center frequencies at 1.5, 2.5, 5 and 6.8 GHz. It was also fabricated and measured with a good agreement with the predicted results.

II. QUAD-BAND MICROSTRIP BANDSTOP FILTER

A. Resonator Analysis

As is well known, open loop resonators having loading elements exhibit dual-mode resonator property. Therefore, multi band bandstop filter may be designed based on this dual resonance property with a proper coupling between I/O ports. For this purpose, open loop resonator with ideal lumped capacitors is firstly analyzed through even/odd mode impedance analysis. I/O ports are connected to each other through a transmission line and the open loop resonator is coupled to this line as a unit cell. In these equations, electrical lengths of $\theta1$ and $\theta2$ correspond to the transmission lines with the lengths of $l1$ and $0.5l2$, respectively, and Zr is the characteristic impedance of these lines. It should also be noted that the characteristic impedances of the transmission lines in the coupling section are equal. Moreover, Zx and Zy may be expressed as,

$$Z_x = \frac{Z_{0e} + Z_{0o}}{2}$$

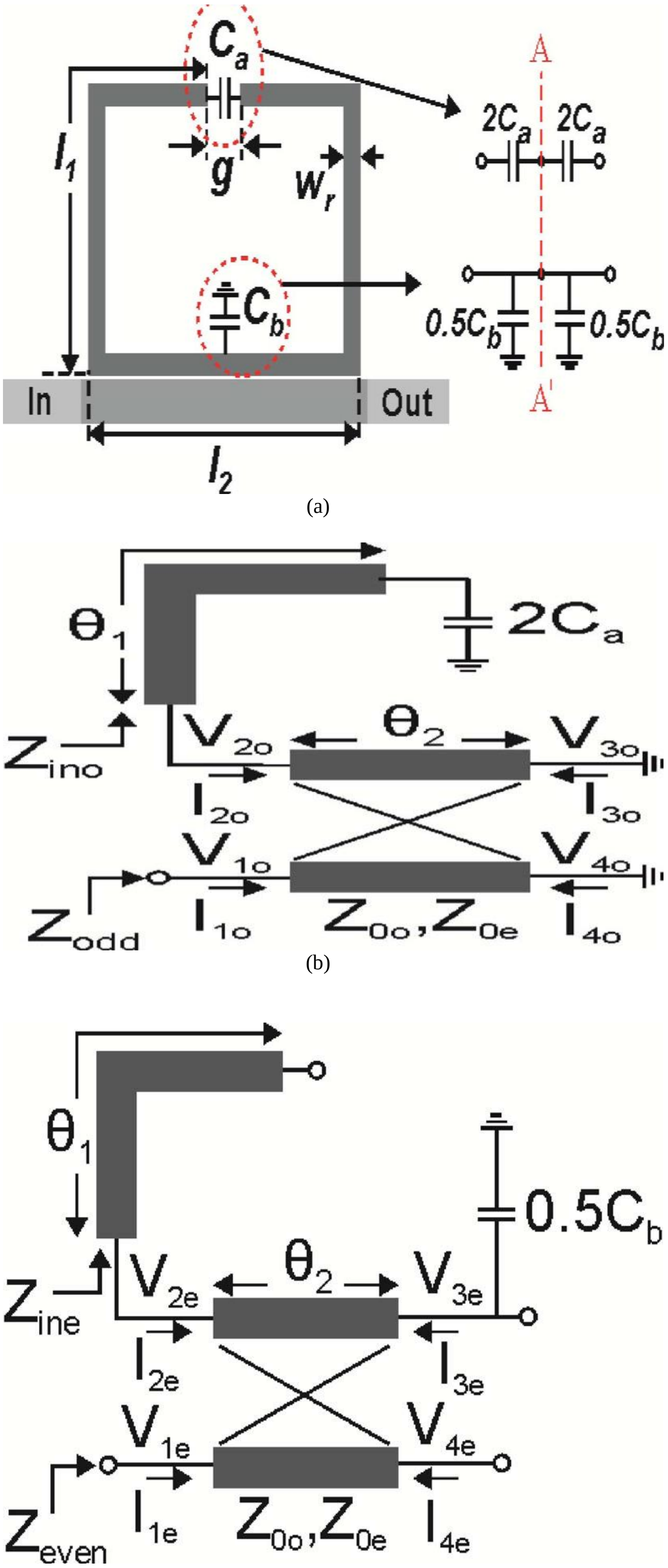
$$Z_y = \frac{Z_{0e} - Z_{0o}}{2}$$

where, Z_{0e} and Z_{0o} denote the even and odd mode characteristic impedances, respectively, and they can be calculated according to [1]. Even/odd mode resonance frequencies may be derived from the resonance conditions, ($Y_{even} = 0$, $Y_{odd} = 0$), as

$$f_{even} = -\frac{1}{\Pi C_b Z_x} \tan\left(\theta_2 + \arctan\left(\frac{Z_x}{Z_r}\tan\theta_1\right)\right) \tag{3a}$$

$$f_{odd} = -\frac{1}{\Pi C_b Z_r} \tan\left(\theta_1 + \arctan\left(\frac{Z_x}{Z_r}\tan\theta_2\right)\right) \tag{3b}$$

According to Eqns. (3a) and (3b), it should be noted that the even and odd mode resonance frequencies can be independently controlled by Ca and Cb, respectively. Effects of length ratio of $\theta1$ and $\theta2$ at different capacitances are depicted in Fig. 2a. On the other hand, asymmetry of coupling section only affects the locations of reflection zeros without changing the even and odd mode resonances. As shown in Fig. 2b, while the feedline width is greater than the resonator width, two reflection zeros can be adjusted between the resonances. In case of smaller feedline width, reflection zeros can be adjusted at the left and right sides of the even and odd mode resonances, respectively.

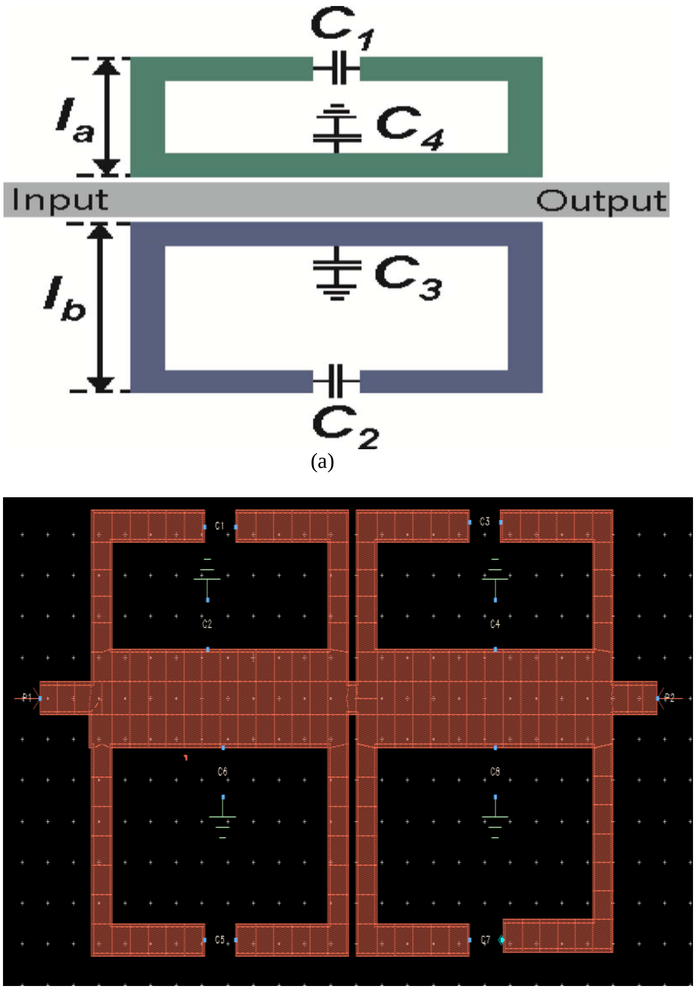


(a)

(b)

(c)

Fig. 1. (a) Proposed resonator structure as a unit cell, and equivalent circuit
models of the proposed structure (b) even mode (c) odd mode.



(a)

(b)

Fig. 2. (a) The filter structure for a single unit cell (b) Layout of 4 unit cell structure for simulation

In addition, reflection zeros are overlapped while the line widths are equal. For Fig. 2a and 2b, dimensions shown in Fig. 1a are, *wr* = 0.8, *l*1 = 7.8, *l*2 = 10.0, *g* = 1.2, in mm, and *Ca* = 0.9, *Cb* = 4.7, in pF. Full-wave Electromagnetic Simulator is used in all simulations [9].

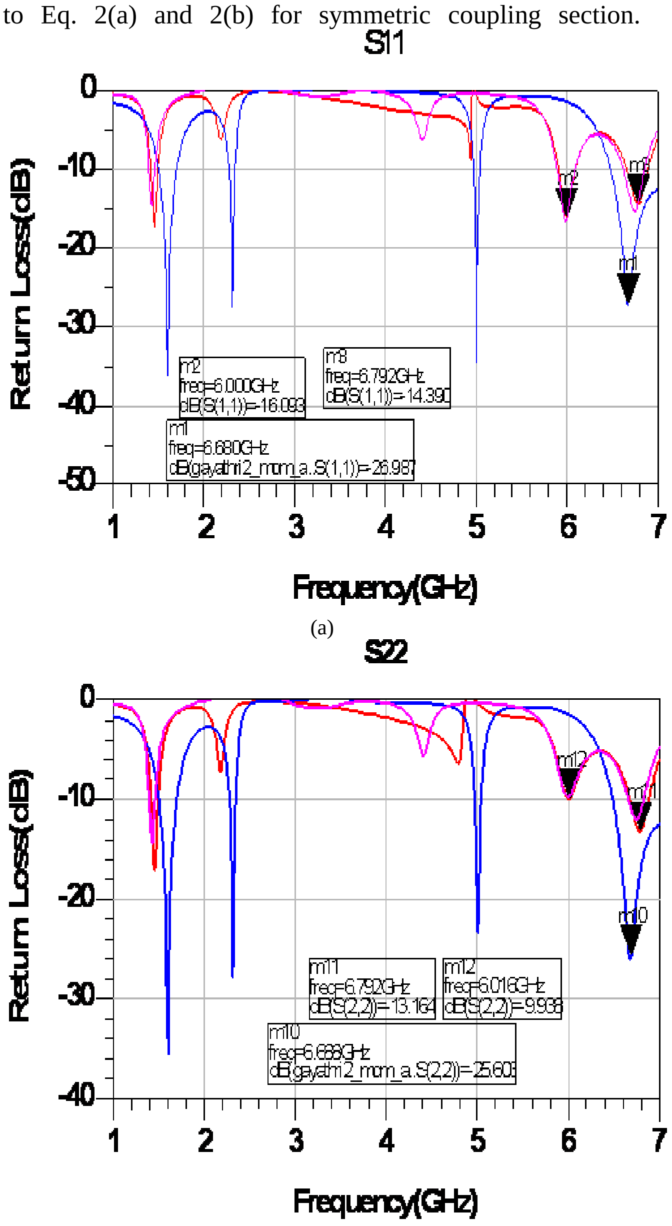
B. Filter Design

The proposed filter is designed on RT/Duroid substrate with a relative dielectric constant of 10.2 and a thickness of 1.27 mm.

Fig. 3b illustrates the frequency response of the quad-band filter for a single unit cell. Relation between the capacitances and the resonance frequencies is depicted in Fig. 3c. According to this figure, by changing *C*1 and *C*2 between 0 and 4 pF, resonance frequencies of the first and second stopbands may be adjusted between 0.7 and 2.7 GHz, respectively. In addition, resonance frequencies of the third and fourth stopbands can also be controlled between 2.06 and 3.5 GHz depending on the changes in *C*3 and *C*4 between 2 and 50 pF, respectively. Therefore, a frequency range between 0.7 and 3.5 GHz can be easily covered by varying the capacitances. In Fig. 3c, all stopband frequencies can only be controlled by the related capacitors.

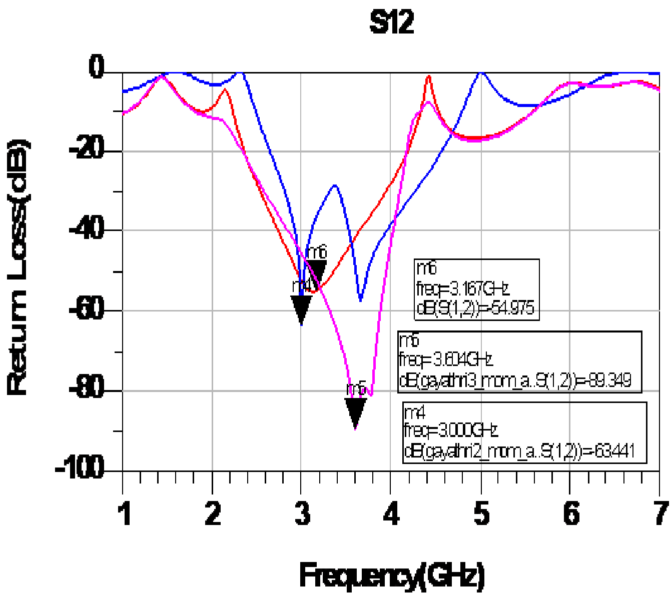
III.RESULTS AND DISCUSSION

Taking into account the proposed method, a quad-band bandstop filter with higher degree and higher selectivity can be designed by using two cells as shown in Fig. 2b. The secondary unit cell brings one more reflection zero near the stopbands and also one more transmission zero in each stopband. Distance between the resonators affects the bandwidth and locations of reflection zeros of each passband as depicted in Fig. 2b. The distance between the unit cell choosen for our work is 4cm (*d*). The reflection poles inside the stopbands can also be split by changing *d*. It should also be noted that, since *wf (1.2mm)* changes the locations of reflection zeros, it may also change the selectivity of the stopbands. As a summary of the design procedure; firstly decide the stopband frequencies and determine the electrical lengths and capacitances according to Eq. 2(a) and 2(b) for symmetric coupling section.

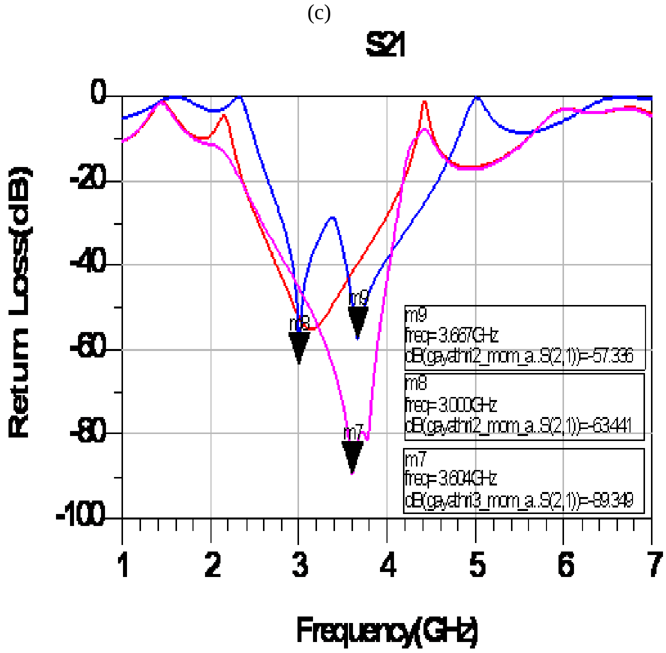


(a)

(b)



(c)



(d)

Then, decide the locations of reflection zeros and assign the feedline width. Finally, place two identical resonators as shown in Fig.2b and the distance between the identical resonators must be assigned due to the desired bandwidths and reflection zeros. Center frequencies of the stopbands are adjusted to 1.5, 2.5, 5 and 6.8 GHz with the fractional bandwidths of 4.286%, 4.456%, 4.2%, 4.16%, respectively. Simulated rejection levels and minimum return losses at each stopband are 26.6/22.8/31.9/39.7 and 1.38/1.45/1.97/1.9 dB, respectively. According to this figure, by changing $C1$ and $C2$ between 0.9pF and 0.2pF, resonance frequencies of the first and second stopbands may be adjusted between 2.2 and 3 GHz, respectively. In addition, resonance frequencies of the third and fourth stopbands can also be controlled between 2.8 and 4.8 GHz depending on the changes in $C3$ and $C4$ between 9.1pF and 5.1 pF, respectively. The designed filter has lower return loss in all four resonant bands as shown in figure.3. Figure 3(a) to (d) shows the return loss range for the width of unit cell of 0.8,0.3 and 1.3mm in four resonant bands. The effect of changing the width of unit cell has been studied. Simulated rejection levels and minimum return losses at each stopband are 26.6/22.8/31.9/39.7 and 1.38/1.45/1.97/1.9 dB, respectively. Center frequencies of the measured response are 2.3, 2.4, 4.8 and 6.8 GHz with the fractional bandwidths of 4.286%, 4.456%, 4.2%, and 4.16%, respectively.Since the designed bandstop filter has four independently controllable center frequencies in a wide range between 0.7 and 3.5 GHz, it has significant advantages as compared to quad-band bandstop filters in the literature. The designed filter has also an important advantage in terms of return losses at the stopbands.

IV.CONCLUSION

A quad-band microstrip bandstop filter is designed based on the dual-mode properties of open loop resonators. Lumped capacitors are used to control the mode frequencies of open loop resonator. Four different resonance frequencies are obtained by means of two open loop resonators in different electrical lengths. After that, two unit cells are located to obtain higher degree inside the stopbands. While the designed filter allows controlling center frequencies independently, bandwidths and rejection levels cannot be independently controlled.

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