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Research Article

Design of Folded Multilayer Microstrip Tri-Band Hairpin Band Pass Filter

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Abstract: This study presents a novel approach for realizing miniaturized multi layer folded tri band micro-strip band pass filter for Wireless Local Area Network (WLAN) and Worldwide interoperatability for Microwave Access (WiMAX) applications. The proposed filter consists of a pair of folded hairpin stepped impedance resonators and pair of open loop resonators to achieve tri-band performance. The size of the folded micro-strip tri-band filter is reduced by nearly 60% due to the structural folding arrangement of SIR compared with conventional multilayer triband filter. The folded hairpin resonator helps to reduce the size of the filter. The stepped impedance resonators are designed to operate at the first and third pass bands and the open loop resonators at the second pass band. The design methodology of the tri-band band pass filter was presented. The simulated results of proposed tri-band filter were compared with the conventional one and tabulated.

Keywords: Folded resonator, open loop, pass band, size reduction, stepped impedance, wireless

INTRODUCTION

The BPF plays a key component to select the desired signals in the radio frequency front end devices. In radio frequency devices of the wireless communication systems, multiple service technology is aggressively developed. In recent years, the RF circuit topology with high integration of multiband has become more important to access different services with a single multimode terminal. Wireless local area networks and WiMAX operate at frequencies of 2.4/5.2 GHz and 3.5 GHz. A multi band RF front end is required to accommodate this RF signal transmission and reception in to a single RF transceiver. By switching between three separate filters this single RF transceiver for tri-band can be designed. But this topology requires more number of filter components and thus leads to enlarged circuit size and increased power consumption. The RF circuits operating in different bands are integrated in to a single unit to achieve multiband filter with reduced size and cost. This filter has the distinct feature of simultaneous pass bands at separate centre frequencies with sufficient out of band suppression.

In modern microwave communication systems small size BPFs with high performance, low insertion loss and potential integration with other planar circuits are finding increasing applications. Several multiband filters have been reported with new innovative designs. To realize multiband responses, Stub Loaded Resonators (SLR), Substrate Integrated Waveguides (SIW) and Stepped Impedance Resonators (SIR) were used in the topologies of filter design. SIW was used to design tri band BPF with Low Co-Fired Ceramic (LTCC) technology (Tsai and Wu, 2011). Dual band and tri band filters designed using inverter coupling resonators were reported by Chen *et al*. (2007). Two pass bands were realized using single line SIR with coupled open stub resonators (Chen *et al*., 2011). Open loop resonator and defected stepped impedance resonator were used for the implementation of dual band filter (Lai *et al*., 2010). Dual band BPF using a pair of asymmetrical resonators was proposed by Weng *et al*. (2011). A tri band filter consisting of 3 split ring resonators was proposed (Luo *et al*., 2011). Tri-band BPF designed using stub loaded resonators and DGS was reported by Lai *et al*. (2010).

The tri-band filters are important components in tri-band receiver. Several design approaches have been proposed for the design of tri-band band pass filters. Nowadays tri-band filter has been realized using a SIR due to their multiband property. A two pole tri-band filter was realized using short stub loaded stepped impedance resonator (Xuehui *et al.*, 2011). The SIRs were bent into hairpin structure to construct compact filter. Asymmetric stepped impedance resonators were used for the design of tri-band BPF (Chen *et al.*, 2011). U-shape defected ground structure and coupled lines were added to improve the performance of filter. A tri-band BPF realized using open stub and short stub loaded resonators was reported by Li and Wei (2012). The tri-band filter designed using asymmetric dual

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quarter wavelength resonators with common via was presented (Fei *et al*., 2012).

In wireless communication systems multilayer filter plays an important role to reduce the size, cost and to enhance the system performance (Cho and Gupta, 2007). The microwave circuits designed using multi layer configurations are compact and have more design flexibility. Multi layer band pass filter designed using open loop resonators was reported by Clavet *et al.* (2007).

Several researchers have reported on size reduction of filters. A compact four pole BPF based on multifold miniaturized hairpin line resonators was proposed by Jagdish and Jain (2012). The filter has cross coupled structure with 60% size reduction compared to conventional hairpin resonators. A miniaturized dual mode band pass filter was designed using fractal shaped open stub resonators (Jawad and Alsaedi, 2012).

Various structures have been proposed for designing compact reduced size filters such as open line resonator filters, filters with stub, closed loop resonator filters. Among the various filter structures hairpin line resonators are widely used since it has the flexibility of folding the resonators in to a more compact form and simple design methodology. Another advantage is to control the band width easily.

In this study a new type of BPF with reduced size based on folded hairpin SIR and open loop resonators has been proposed in multilayer configuration. The comparison between folded multilayer filter and conventional multi layer filer is presented to demonstrate the miniaturization. The proposed filter has compact size rather than planar filters due to its multilayer configuration. In addition the folded resonators used for the design of filters make the filter more compact.

THEORY

Characteristics of folded miniaturized hairpin resonator: Figure 1 shows the miniaturized hairpin resonator. This structure enables a compact BPF design and increases design flexibility. A half wavelength resonator with open ends possesses a maximum electric field distribution near both open circuited ends at resonance. The phase difference of both ends is π radians at fundamental resonant frequency f_0 and zero radians at the following higher order mode of resonant frequency $2f_0$. A SIR with internal coupled lines generate an odd mode field distribution at fundamental resonant frequency and even mode field distribution at the following higher order mode $2f_0$. A hairpin SIR with coupled lines can be expressed as a conventional SIR composed of two single transmission lines. The resonance condition are expressed as:

Even mode:

$$tan\theta_s . tan\theta_{po} = R_{zo} = \frac{Z_{po}}{Z_s} \qquad (1)$$

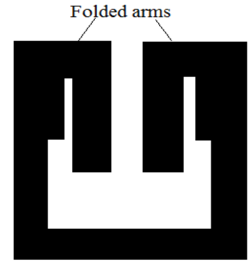

Fig. 1: Folded miniaturized hairpin resonator

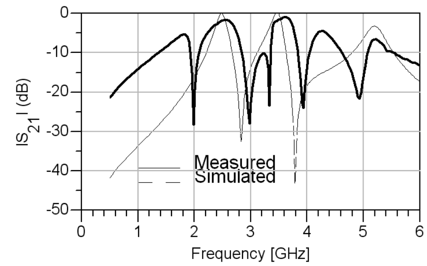

Fig. 2: Measured and simulated response of conventional tri-band filter

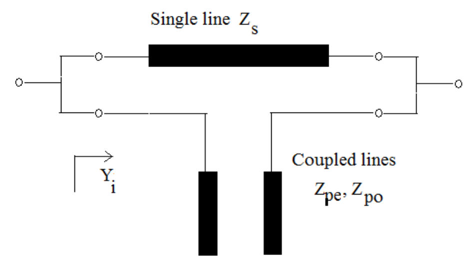

Fig. 3: Equivalent circuit of miniaturized hairpin resonator

Odd mode:

$$tan\theta_s . tan\theta_{pe} = R_{ze} = \frac{Z_{pe}}{Z_s} \qquad (2)$$

Even and odd mode impedance of parallel coupled lines are represented by Z_{pe} *and* Z_{po}. The even and odd mode coupling angle of parallel coupled lines are θ_{po} *and* θ_{pe}. The single mode impedance and the corresponding coupling angle are Z_s *and* θ_s. Figure 2 shows the equivalent circuit of hairpin SIR with internal coupled lines. This circuit can be analyzed as a parallel connection of a single transmission line and parallel coupled lines with open ends. R_{zo} *and* R_{ze} are impedance ratios of odd and even modes respectively. The frequency response of a filter can be derived from the ABCD matrix of the equivalent circuit shown in Fig. 3. The ABCD matrix of the filter designed using this single resonator is:

$$F = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

$$= \begin{bmatrix} \frac{Z_{pe} \cot\theta_{po} + Z_{po} \cot\theta_{po}}{Z_{pe} \cot\theta_{pe} - Z_{po} \cot\theta_{po}} & \frac{-j \; 2Z_{pe} \cot\theta_{po} Z_{po} \cot\theta_{po}}{Z_{po} \cot\theta_{pe} - Z_{po} \cot\theta_{po}} \\ \frac{j\,2}{Z_{pe} \cot\theta_{pe} - Z_{po} \cot\theta_{po}} & \frac{Z_{pe} cot_{pe} + Z_{po} cot_{po}}{Z_{pe} \cot\theta_{pe} - Z_{pe} \cot\theta_{po}} \end{bmatrix} \quad (3)$$

Based on the results obtained from the relationship between total resonator length and single line length it is obvious that a lower impedance ratio R_z and greater coupling coefficient C are required for better miniaturization. The minimum resonator length can be achieved for a constant R_z and when $\theta_s = \theta_p$, it is equivalent to that of conventional SIR without coupled lines.

DESIGN OF FOLDED HAIRPIN FILTER

In this study the design method for proposed multi layer band pass filter is presented. The configuration of proposed folded hairpin SIR BPF is demonstrated in Fig. 4. Hairpin resonators have been combined with open loop resonators in multi layer configuration to make the filter in compact size. The two dimensional view of the proposed filter is depicted in Fig. 5. Hairpin resonators are allocated on top layer and the uniform impedance open loop resonators are constructed on the middle layer. The folded arrangement of hairpin stepped impedance resonators make the filter more compact and results in very small filter size.

To achieve tri-band performance multi layer technique is adopted. The substrate material used for the design of tri-band BPF is FR4 with the dielectric constant of 4.1 with the thickness of 1.5 mm. The width of the feed line is kept 3 mm to match the characteristic impedance of 50 ohms. The filter geometry has three layers namely upper strip layer, middle strip layer and ground layer. Two dielectric layers are stacked between the conducting layers. Dielectric substrate material is completely filled between the layers. The thicknesses of two dielectric substrate layers are assigned to be equal in this design.

The two arms of hairpin line resonators are further folded inside to form open circuited coupled line. The

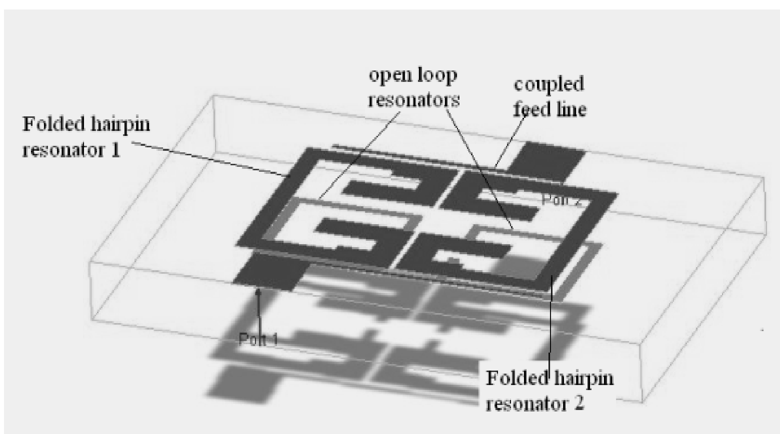

Fig. 4: Three dimensional view of folded hairpin filter

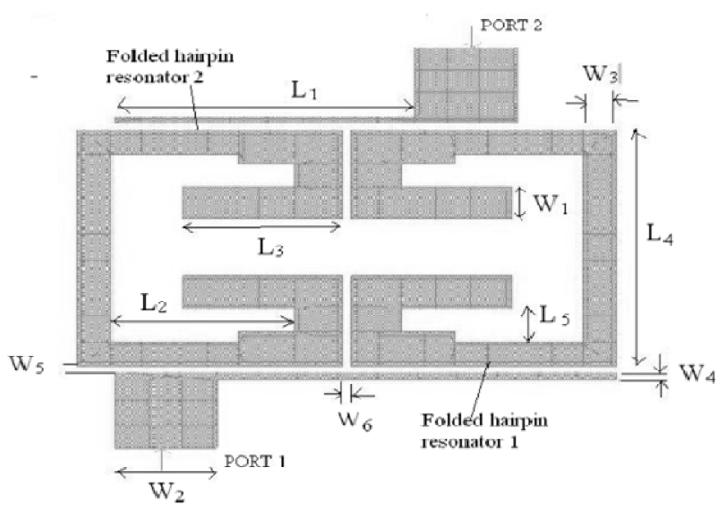

Fig. 5: Two dimensional view of folded hairpin filter

size of the filter incorporating these folded resonators is reduced to 60% of the filter designed using conventional hairpin resonator. To create an interesting topology for WLAN and WiMAX applications and to reduce the size of hairpin resonator, the arms of the hairpin line resonators are reactively loaded with parallel coupled lines. Filters designed using this miniaturized hairpin resonators are more compact than the filters designed using conventional hairpin resonators. The inter coupling introduced by the parallel coupled lines of miniaturized hairpin resonators create an extra transmission zero near the pass band edge which in turn improves the selectivity of the filter.

RESULTS AND DISCUSSION

A conventional and proposed folded multilayer BPFs were designed and analyzed for comparison. Both the filters are designed for the centre frequencies of 2.4/3.5/5.2 GHz and designed using a pair of hairpin resonators on top layer and a pair of open loop resonators on middle layer. The conventional filter is designed on RT/Duroid substrate with the dielectric thickness of 0.7 mm and dielectric constant of 2.2. The three dimensional view and the photograph of the fabricated conventional filter are shown in Fig. 6 and 7 respectively. The simulated and measured results of conventional filter are shown in Fig. 2. The conventional filter has three pass bands. The first and third pass bands are controlled by changing the electrical length of SIRs and the second pass band can be tuned by adjusting the dimensions of open loop resonators. Half wave length stepped impedance resonators on the top layer are bent to form the hairpin resonators to have the total size of filter as 32×22 mm^2. The proposed filter is designed on FR4 substrate with the dielectric constant of 4.1, loss tangent of 0.022 and thickness of 1.5 mm. ADS 2009 software is employed to simulate the scattering parameters of proposed tri-band filter. In contrary to the conventional filter, hairpin resonators are folded in the proposed filter. The arms of hairpin resonators are folded inside to achieve an optimum size of filter. The proposed filter has a size reduced by 60% compared to the conventional filter. The overall dimension of the designed filter is 15×15 mm^2. The dielectric constant of proposed filter is higher than that of conventional one. The higher dielectric constant value reduces the electrical length of SIR which in turn reduces the size of the filter. The physical parameters of the filter structure are the followings. L_1 = 8.7 mm, L_2 = 5.3 mm, L_3 = 4.8 mm, L_4 = 10 mm, L_5 = 1.4 mm, W_1 = 1.4 mm, W_2 = 3 mm, W_3 = 1 mm, W_4 = 0.3 mm, W_5 = 0.3 mm, W_6 = 0.3 mm. The characteristic impedances of high and low impedance sections of stepped impedance hairpin resonator are Z_1 = 80 and Z_2 = 105 ohms. The characteristic impedance and line width of open loop resonators are 107 ohms and 0.6 mm, respectively. The impedance ratio of half wavelength stepped impedance resonator is chosen to be 0.86. The size of SIR is comparatively reduced since the impedance ratio value is less than 1.The corresponding electrical length of the low and high impedance sections of SIR is 42.9°. Figure 8 shows the variation of scattering parameters of folded hairpin filter with frequency. It is apparent from the figure that the proposed filter has three pass bands with the centre frequencies of 2.4/3.5/5.2 GHz. The first and

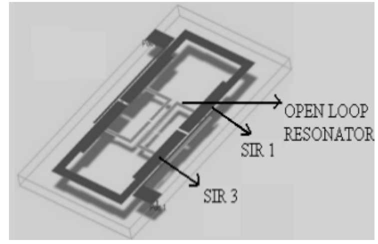

Fig. 6: Three dimensional view of conventional tri-band filter

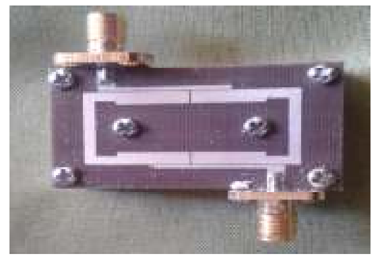

Fig. 7: Photograph of conventional tri-band filter

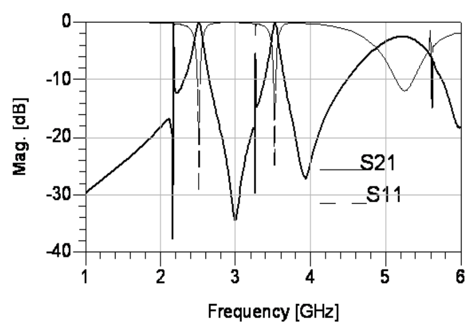

Fig. 8: Simulated response of folded hairpin filter

Table 1: Comparison of conventional and proposed tri-band multilayer filter

Filter parameters	Conventional filter	Proposed miniaturized filter
Centre frequency (GHz)	2.4/3.5/5.2	2.4/3.5/5.2
Filter configuration	Multilayer	Multilayer
Dielectric substrate	RT/Duroid 5880	FR4
Dielectric constant	2.2	4.1
Size (mm^2)	22×32	15×15
Insertion loss (dB)	0.5/0.5/4 (simulated)	0.5/0.5/3
Return loss (dB)	23/24/11 (simulated)	29/25/13
Size factor	1	0.34

third pass bands are realized by folded hairpin resonators and the second pass band is realized by open loop resonators. The insertion loss at the three pass bands are 0.5/0.5/3 db respectively. The return losses at the three pass bands are better than -16/-17/-9 db respectively. The results of conventional and proposed filter are compared and presented in Table 1. According to the results it is proved that the proposed filter has better return and insertion loss compared to conventional one. In addition the area occupied by the proposed filter is about 15×15 mm^2 where as the conventional filter occupies the area of about 32×22 mm^2 on its substrate which results in the size reduction of 60%.

CONCLUSION

This study presents a new design technique for realizing miniaturized micro-strip band pass filter on multi layer configuration. The new band pass filter consists of folded stepped impedance hairpin resonators and open loop resonators on two layers backed by conductor. Effective Size reduction is achieved using multilayer technology. Further size reduction is obtained by using miniaturized folded hairpin resonators. The proposed filter is of compact size and has good pass band performances, low insertion and return loss compared to conventional filter. The newly designed miniaturized multilayer filter is suitable for WiMAX and WLAN applications.

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