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A new miniature microstrip two-layer bandpass filter using aperture-coupled hairpin resonators

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ABSTRACT

In this paper, a new miniature microstrip bandpass filter using aperture-coupled hairpin resonators is presented. The proposed filter is composed of five U-shaped hairpin resonators located on two stacked microstrip layers. The different couplings between the resonators on the upper layer and those on the lower one are achieved via two aperture etched on a common ground plane located between the two layers. A full-wave simulator is used to design the proposed structure and determine the dimension of the apertures. As a result, a five-pole hairpin bandpass filter was designed and optimized at 2.45 GHz. The use of this multilayer technique allows a significant size reduction of about 40 %.

1. Introduction

In modern wireless communication systems, bandpass filters are playing essential roles. Planar filters are suitable structures because they can be fabricated using PCB technology. During the last two decades, planar filters with various configurations and resonator types have been suggested and investigated (Pozar, 1998). These filter designs have attracted board attention in microwave applications, due to their small size, low insertion loss, high selectivity and their low cost integration. To reduce the resonator size, several shapes of resonators have been suggested. However, all of them are still too large structures and need to be miniaturized. To achieve this feature, various types of resonators such as: U-shaped hairpin resonator (Hong and Lancaster, 2001; Hong and Lancaster, 1998), the open loop resonators (Cristal and Frankel, 1972) and Stepped Impedance Resonators (SIR) (Kong and Chew, 2005), have been considered as an effective solution to filter miniaturization. However, these configurations are implemented on a single-layer structure. Therefore their size is still too large. To resolve this problem, multilayer filter designs become suitable approaches for filter-size miniaturization. In these approaches, Open-loop square resonators have been used (Hong and Lancaster, 1999). In the same issue, other two-layer structures have been investigated using Stepped-Impedance-Resonator (SIR) (Djaiz and Denidni, 2005). However, in these previous approaches, the use of different apertures is necessary and thus the tuning of the dimension becomes somewhat hard.

In this paper, a new compact size five poles microstrip bandpass filter using two-layer structure with aperture-coupled hairpin resonators operating at 2.45 GHz is proposed and investigated. The proposed filter configuration consists of five hairpin resonators etched on two stacked layer substrates, and the coupling between the resonators in the upper layer and those in the lower one are achieved by introducing two slots in the common ground plane.

Section 2describes the design approach used to miniaturize the dimensions of the filter characterizes and examines the different couplings used in the filter design. Section 3 describes the resonance properties of the filter design and Simulation implementation. To examine the filter characteristics, numerical results are presented also in Section 3. In addition, a five-pole inter-coupled multilayer microstrip miniaturized hairpin bandpass filter is designed and optimized. Conclusions are followed in Section 4.

2. Design approach

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To demonstrate our approach, a five-pole U-shaped hairpin resonators bandpass filter was designed with specifications listed in Table 1.

Table 1: The proposed bandpass Filter specifications

Center frequency (f_0)	2.45 GHz
FBW (%)	5 %
Insertion Loss (dB)	3 dB maximum
Bandwidth (at -3dB)	120 MHz
Stopband rejection (dB)	< -30 dB

The proposed filter is designed to have a fractional bandwidth (FBW) of 5 % and a mid-band frequency f_0 equals to 2.45 GHz. A five poles Chebyshev low pass prototype filter with a bandpass ripple of 0.1 dB is chosen.

To achieve these specifications, a five hairpin resonators located on two stacked microstrip layers.

The coupling between the resonators on the upper, layer and those on the lower one is achieved by using two coupling apertures etched on a common ground plane located between the two layers. Fig. 1 shows the exploded view of the proposed stacked five-pole bandpass filter of aperture-coupled hairpin resonators that are located on the outer sides of the dielectric. Where h is the substrate thickness; dx and dy are the dimensions of aperture on the common ground plane. Fig. 2 shows the layout for both single- and double-layers of the proposed five-pole bandpass filter.

To Design this filter, numerical simulations using a full-wave simulator; Advanced Design System (ADS) for HP-Agilent were performed to simulate the frequency responses of these basics coupling, and therefore to obtain the different spacing between resonators and the dimensions of the coupling apertures.

Fig. 3(a) shows the typical resonant responses between the second and the third or the third and the fourth coupled resonators. However, Fig. 3(b) shows the typical resonant responses between the first and the second resonators or between the fourth and the fifth resonators. The coupling coefficient can be then extracted by using the following relation (Eq. 1)(Djaiz and Denidni, 2006).

$$K_{ij} = \mp \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} \qquad (1)$$

where f_e, and f_m are the two split resonant frequencies.

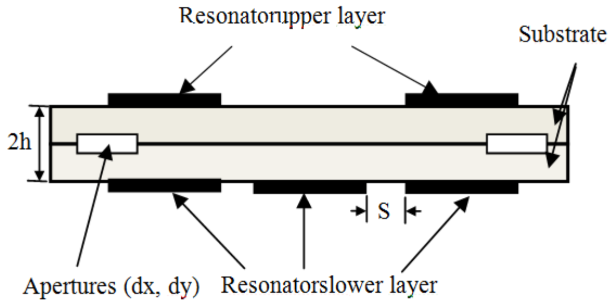
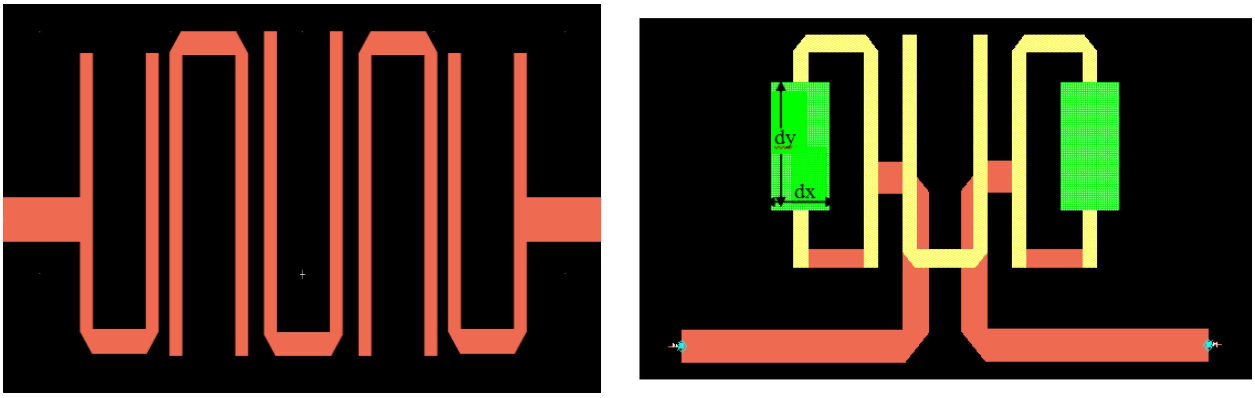


Fig. 1: Structure of proposed filter



(a) (b)

Fig. 2: Layout of (a) conventional filter, (b) proposed filter

The proposed bandpass filter uses U-shape hairpin resonators. To produce necessary coupling between adjacent resonators, these resonators were placed near each other in specified space S.

3. Results and discussions

To demonstrate our approach, the proposed five pole bandpass filter using identical miniaturized hairpin resonators is designed in the ISM band with center frequency f_0 at 2.45 GHz, the passband bandwidth of 150 MHz (FBW= 5 %). The stopband rejection of 20 dB at +70 MHz from the center frequency. This rejection is achieved in the design by replacing the transmission zero at 75 MHz from the center frequency. The circuit was designed and optimized using a substrate with relative dielectric of ε_r = 6.15, a loss tangent of 0.0027, and a thickness of 50mil (1.27 mm).

The filter could be synthesized using the method reported in Levy (1976) from which the lumped-element values of low pass prototype filter were determined as:

$$g_0 = g_6 = 1,\ g_1 = g_5 = 1.1468,\ g_2 = g_4 = 1.3712,\ g_3 = 1.975$$

The coupling coefficients and Q_{ext} can be calculated as follows (Eqs. 2-4):

$$Q_{ext} = \frac{g_0 g_1}{FBW} \qquad (2)$$

$$M_{1,2} = M_{4,5} = \frac{FBW}{\sqrt{g_1 g_2}} \qquad (3)$$

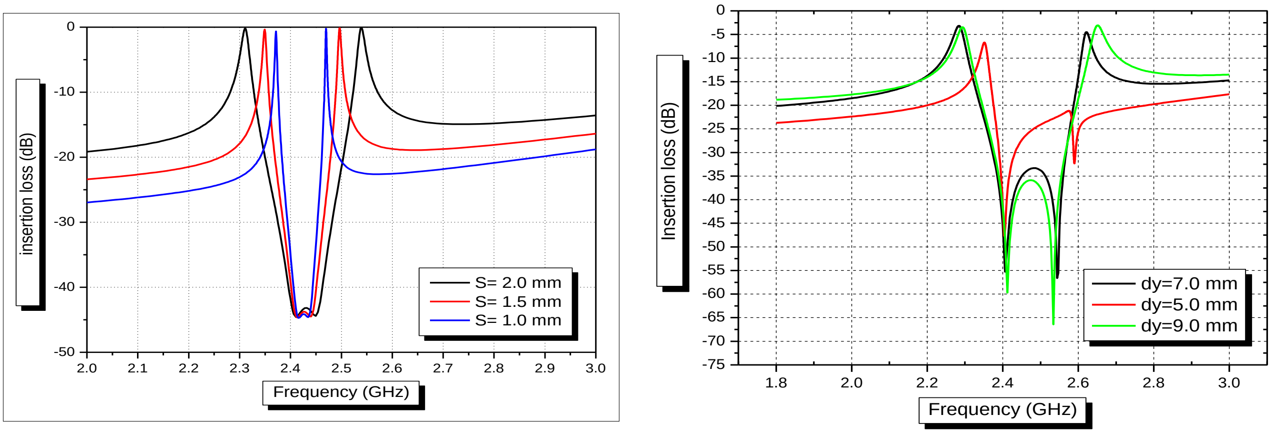
$$M_{2,3} = M_{3,4} = \frac{FBW}{\sqrt{g_2 g_3}} \qquad (4)$$

The coupling coefficient $M_{1,2}$ and $M_{4,5}$ values are used to determine the dimensions of the apertures (dx, dy), between the resonator 1 and 2 resonators, 4 and 5 respectively. The coupling coefficient $M_{2,3}= M_{3,4}$ is used to find the spacing between the resonators 2 and 3. The Input/output loads are achieved via tapped feed lines. Fig. 4 shows coupling coefficients of the different spacing (Figs. 5-7).

As shown in Fig 5. It can be noted that the bandwidth of the proposed filter inversely varies with the spacing between resonators.

Based on the design approach, a five poles U-Shape hairpin resonator bandpass filter prototype using two layers was fabricated. The filter prototype was built using a substrate with relative dielectric constant ε_r = 6.15, a loss tangent of 0.0027, and a thickness of 50mil (1.27 mm).

Figs. 6(a) and (b) show the photograph of the fabricated two-layer bandpass filters prototype, where only the two resonators on the top layer are visible.



(a) (b)

Fig. 3: Typical resonant responses, (a) Horizontal coupling, (b) Aperture coupling

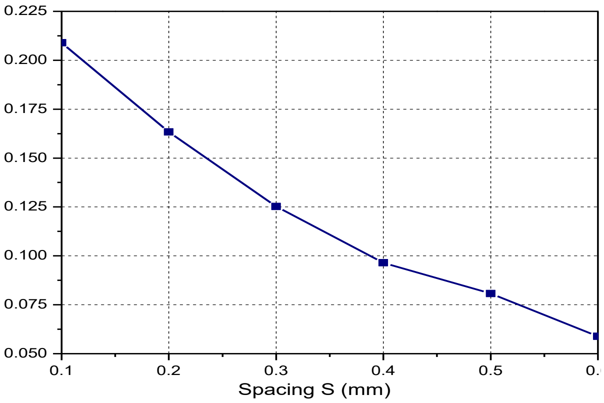


Fig. 4: Coupling coefficients of the different coupling

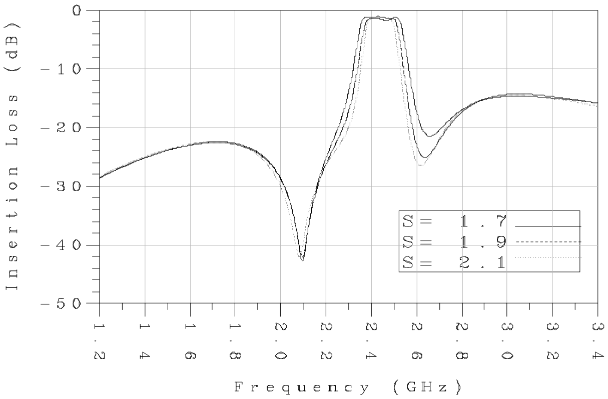
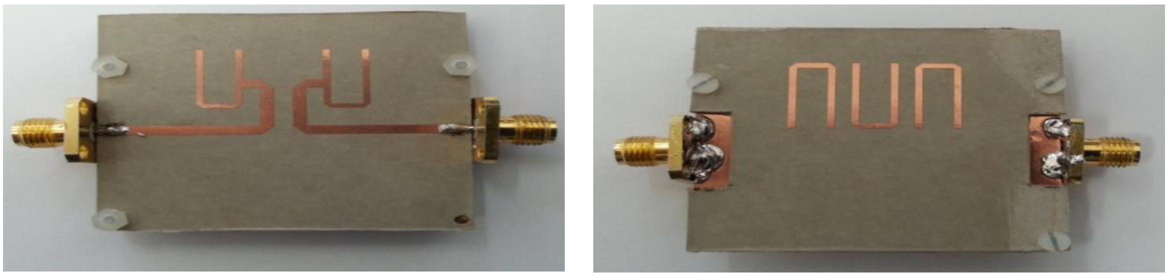


Fig. 5: Bandwidth versus resonator spacing S



(a) (b)

Fig. 6: the photograph of the proposed Filter (a) Upper layer, (b) Lower layer

To examine the performance of the proposed filter, experimental measurements were carried out using an HP8722 network analyzer. Measured filter responses are presented and compared with simulation one.

Figs. 7 and 8 show the simulated and measured S-parameters of the proposed filter. From these curves, it can be observed that a good agreement is achieved between simulation and experimental results. The passband insertion loss fluctuates around 1.65dB, the return loss is less than -11 dB, which is higher than the simulated one (0.8 dB, 15 dB). These small differences are mainly due tothe effect of Input/output SMA connectors, the dielectric conductance, and the resistance of the conductor which were neglected in the simulations. Finally, a fractional bandwidth of 4.75 % at 2.5 GHz is achieved.

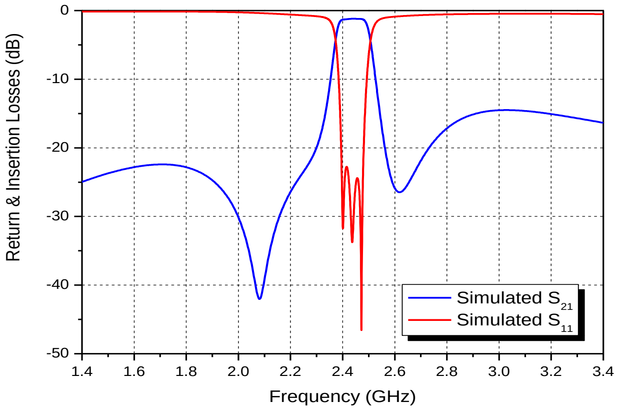


Fig. 7: Simulated S-parameters $S_{11}$and $S_{21}$of the filter

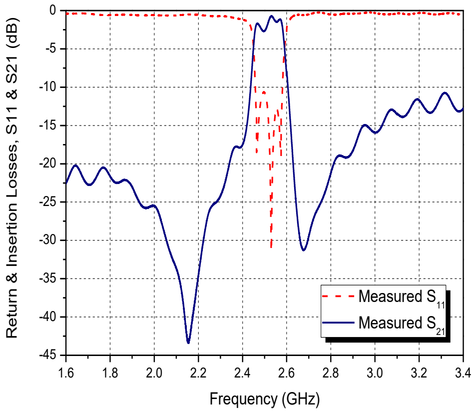


Fig. 8: Measured S-parameters: $S_{11}$and S_{21} of the filter

With such features, the proposed miniaturized filter is suitable for wireless communication systems. It can be seen that the bandwidth of the proposed bandpass filter was slightly wider than the bandwidth in conventional one.

Also, a little frequency shift between the two responses can be observed, which would be attributed to the aperture dimensions precision, and leads to stronger coupling. From these responses, it can be observed two desirable transmission zeros, and symmetrical frequency responses characteristic is obtained.

The proposed filter has a size of 21.8mm X 21.6 mm. This structure produces a 40 % size reduction compared to single-layer filter structure.

4. Conclusion

It can be observed that the bandwidth of the proposed bandpass filter was slightly wider than the bandwidth in conventional one.

Also, a little frequency shift between the two responses can be seen, which would be attributed to the aperture dimensions precision, and leads to stronger coupling. A tapped line Input / Output resonator is chosen due to its high response characteristics. The tapping position is determined using the formula given in Eq. 1. The non-desirable cross couplings are considerably reduced comparing with the research reported in Ralph (Levy, 1976) From these responses, it can be observed two desirable transmission zeros, and symmetrical frequency responses characteristic is obtained. This technique

The proposed filter has a size of 21.8 mm X 21.6 mm. This structure produces a 40 % size reduction compared to single-layer filter structure.Compared with the structure presented in Vidhya and Jayanthy (2011), it can be concluded that, the proposed bandpass filter provides a low insertion loss, good return loss, deeper rejection, and compact size. With such features, the proposed miniaturized filter is suitable for compact wireless communication systems.

5. Conclusion

In this Paper, a new miniaturized five-pole bandpass filter using aperture-couple microstrip U-shape hairpin resonators have been presented.

In the proposed design, the couplings between the resonators have been achieved via two apertures etched in the common ground located between the two layers. Based on this structure, the configuration of the proposed bandpass filter allows a significant reduction of approximately 40% the size of the conventional single-layer bandpass filter.

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