A New Miniature Micro-Strip Two-Layer Band-Pass Filter Using Aperture-Coupled Hairpin Resonators

N. Chami
Electrical Engineering Department
University of M'Sila
Algeria
nourchami@gmail.com

D. Saigaa
Electrical Engineering Department
University of M'Sila
Algeria
djamel.saigaa@univ-msila.dz

A. Djaiz
Electronics and Instrumentation Engineering Technology Department
Yanbu Industrial College
Saudi Arabia
djaiza@rcyci.edu.sa

Received: 3 May 2022 | Revised: 25 June 2022 | Accepted: 29 June 2022

Abstract-The goal of this project was to provide novel band-pass filter design techniques for mobile communications, which allow a significant reduction in the size of the filters produced. The novelty comes from the transformation of the single layer technique into a double layer technique by inserting coupling slots in a common mass plane. Because of their tiny size, these filters are suitable candidates for integration into mobile communication systems. Indeed, when compared to the dimensions of a single-layer planar filter, the multilayer construction allowed us to reduce the size of the filter by more than 40%. Five U-shaped hairpin resonators were placed on two micro-strip layers in the planned filter. Two apertures etched on a common ground plane positioned between the two layers allow varied couplings between the upper and bottom layer resonators. A five-pole hairpin band-pass filter was created as a result.

Keywords-micro-strip filters; miniature circuits; hairpin resonator; multilayer structure; apertures; resonator filters

I. INTRODUCTION

The field of wireless communications is continuously expanding and improving. Indeed, since the introduction of cellular systems, particularly 4G systems [1, 2], downsizing of RF components in general, and filters in particular, has piqued interest and has become a critical requirement. Filtering at 4G operating frequencies is considered a challenge itself: waveguides and, more broadly, three-dimensional (3D) approaches, which are widely used in mobile communications, are not available in 4G cellular networks, whereas planar filters, which are generally not used in 4G systems due to their relatively high losses, tuning difficulties, and low operating powers, become more appealing. Several strategies have been presented to address this demand. Micro-strip line filters are particularly appealing for mobile radio applications due to their efficiency and repeatability [3]. The latest generation of cellular systems is characterized by a constant reduction in cell size. This tendency, on the one hand, increases the market volume of base stations, while, on the other hand, reduces the power supply demand for wireless communication networks [4, 5]. Special attention must be paid in this context to the types and qualities of employed equipment, such as weight and size, which are becoming an increasingly strong limitation for the realization of current cellular telephone circuits [3, 4, 6, 7].

Planar technology has sparked interest in the design of microwave circuits in this context, due to the multiple benefits of these structures, which include low cost, small size, light weight, ease of design, and reproducibility. Filters are also the first, out of all the components, of the microwave block circuit to be explored in planar technology [3].

The current work proposes and investigates a unique five-pole micro-strip band-pass filter with a two-layer structure and aperture-coupled hairpin resonators operating at 2.45GHz [9]. The suggested filter architecture consists of five hairpin resonators etched on two stacked layer substrates, with two slots in the common ground plane providing coupling between the upper and bottom layer resonators [8-10].

II. DESIGN APPROACH

To demonstrate our approach, a five-pole U-shaped band pass filter with hairpin resonators was designed with the specifications listed in Table I. The proposed filter is designed to have a 5% Fractional Bandwidth (FBW) and a median frequency f_0 of 2.45GHz [12-14]. A five-pole Chebyshev low-pass filter prototype with a bandwidth ripple of 0.1dB was chosen. A five-pin resonator on two stacked micro-strip layers was used to meet these requirements. The coupling between the resonators on the upper and lower layers is accomplished by etching two coupling apertures on a common ground plane between the two layers. The proposed stacked five-pole band-pass filter of aperture-coupled hairpin resonators on the outer

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Corresponding author: N. Chami

surfaces of the two dielectrics is shown in exploded view in Figure 1. The substrate thickness is *h*, and the aperture dimensions on the common ground plane are d*x* and d*y*.

TABLE I. THE PROPOSED BANDPASS FILTER SPECIFICATIONS

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

To design this filter, numerical simulations were performed using the full-wave simulator Advanced Design System (ADS) for HP-Agilent [9, 15] to simulate the frequency responses of these fundamental couplings, and thus to acquire the varied spacing between resonators and coupling aperture dimensions. The typical resonant responses between the second and third or third and fourth coupled resonators are shown in Figure 2(a). The typical resonant responses between the first and second resonators, or between the fourth and fifth resonators, are shown in Figure 3(b). The coupling coefficient can be then extracted by using the following relation [8]:

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

where f_e and f_m are the two split resonant frequencies.

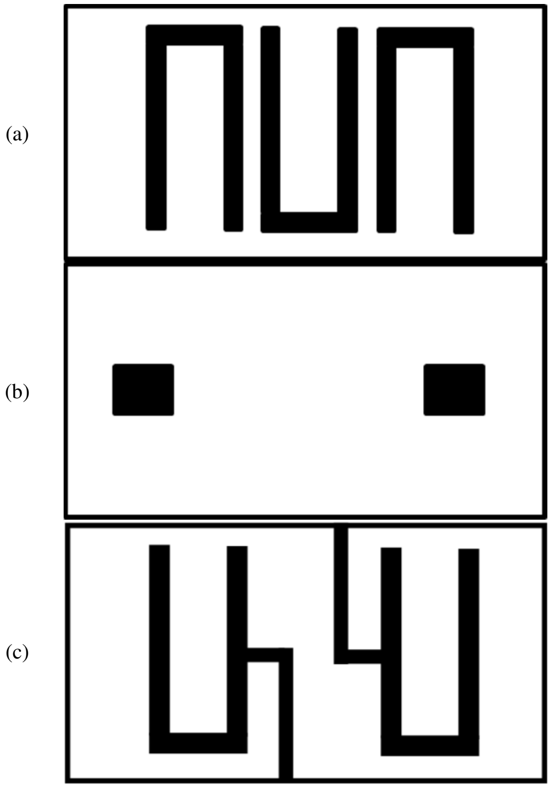

Fig. 1. Structure of the proposed filter.

The proposed Band-pass filter uses U-shape hairpin resonators [15]. To produce necessary coupling between adjacent resonators, these resonators were placed near each other in a specified space S [16].

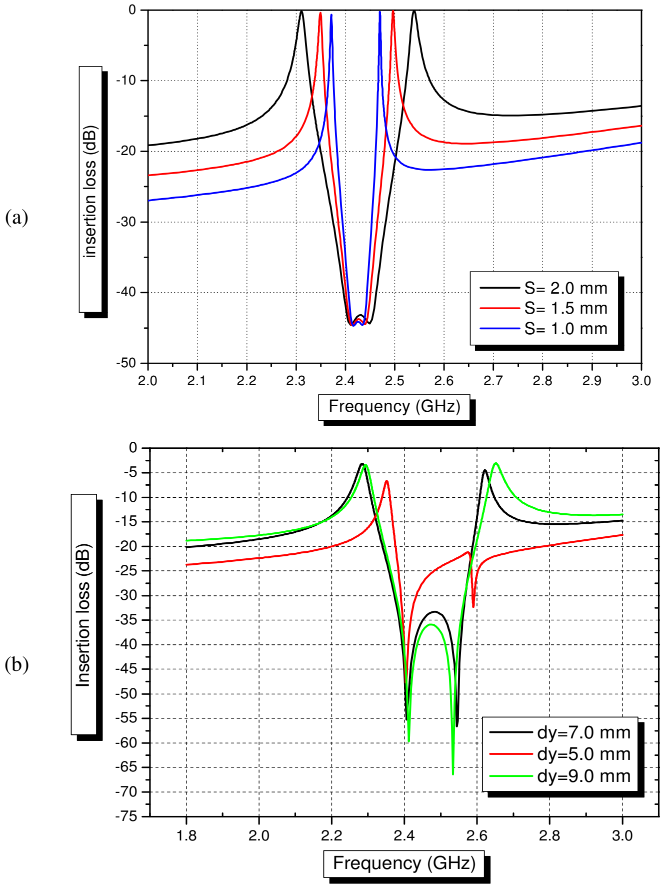

Fig. 2. Typical resonant responses: (a) horizontal coupling, (b) aperture coupling.

III. RESULTS AND DISCUSSION

To demonstrate the proposed approach, the proposed five pole βand-pass filter [17] using identical miniaturized hairpin resonators is designed in the ISM band with center frequency f_o at 2.45GHz, band-pass bandwidth of 150MHz (FBW= 5%), and stop-band rejection of 20dB at +70MHz from the center frequency. This rejection is achieved in the design by replacing the transmission zero at 75MHz from the center frequency [18]. The circuit was designed and optimized using a substrate with relative dielectric of $\varepsilon_r = 6.15$, loss tangent of 0.0027, and thickness 50mil (1.27mm). The filter can be synthesized using the method reported in [10, 19] 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:

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

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

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

The coupling coefficient $M_{1,2}$ and $M_{4,5}$ values are used to determine the dimensions of the apertures (dx, dy), between the resonators 1 and 2 and 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. Figure 3 shows the coupling coefficients of different spacings.

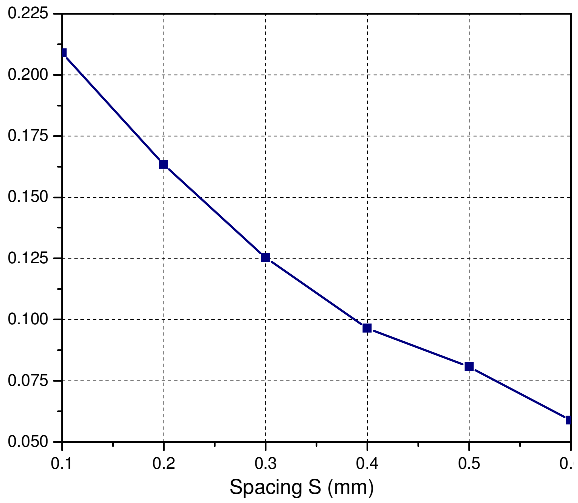

Fig. 3. Coupling coefficients of different couplings.

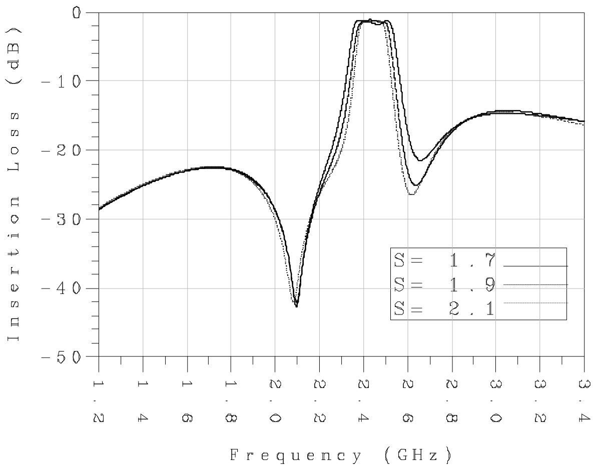

Fig. 4. Bandwidth versus resonator spacing S.

As depicted in Figure 5, it should be noted that the suggested filter's bandwidth varies inversely with the separation between resonators. A five-pole U-shape hairpin resonator band-pass filter prototype with two layers was manufactured utilizing the design technique. Experiments were carried out utilizing an HP8722 network analyzer to evaluate the suggested filter's performance. Filter responses that have been measured are provided and compared to simulation results. Figures 5 and 6 show the simulated and measured S parameters of the proposed filter. From these curves, it can be observed that good agreement is achieved between simulation and experimental results. The band-pass insertion loss fluctuates around 1.65dB, the return loss is less than -11dB, which are higher than the simulated results (0.8dB, 15dB).

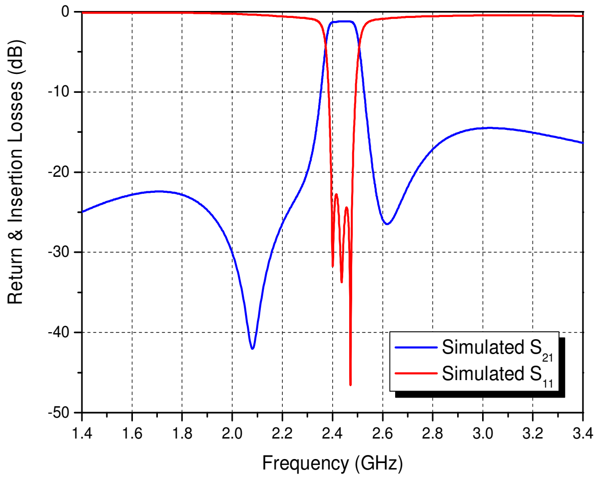

Fig. 5. Simulated S parameters S11 and S21 of the filter.

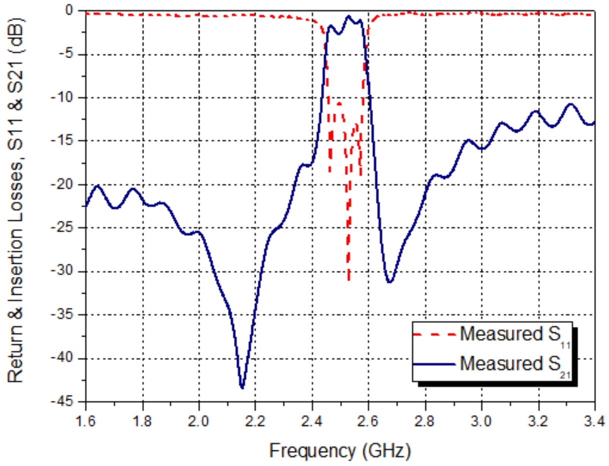

Fig. 6. Measured S parameters S11 and S21 of the filter.

These small differences are mainly due to the effect of input/output SMA connectors, the dielectric conductance, and the resistance of the conductor which were neglected in the simulations [14]. Also, a fractional bandwidth of 4.75% at 2.5GHz is achieved. With such features, the proposed miniaturized filter is suitable for wireless communication systems. It can be seen that the bandwidth of the proposed band-pass filter is slightly wider than that of the conventional filter. Moreover, a slight frequency shift between the two responses can be observed, which should be attributed to the accuracy of the dimensions of the opening, and leads to a stronger coupling. From these responses, two desirable transmission zeros can be observed, and a symmetrical characteristic of the frequency responses is obtained [19]. The proposed filter has a size of 21.8mm×21.6mm. This structure provides 40% reduction in size compared to the single layer filter structure.

IV. CONCLUSION

The goal of this project was to provide a novel band-pass filter design technique for mobile communications. The design procedure allows a significant reduction in the size of the produced filters. The approach's novelty comes from the transformation of a single layer technique into a double layer technique by inserting coupling slots in a common mass plane. Because of their tiny size, these filters are suitable candidates for integration in mobile communications systems. Indeed, when compared to the dimensions of a single layer planar filter, the multilayer construction allowed us to reduce the size of the filter by more than 40%.

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