A Miniaturized Aperture-Coupled Multilayer Hairpin Bandpass Filter

Han-Ul Moon · Seung-Un Choi · Sang-Won Yun

Abstract

In this paper, we introduce a coupling, which is achieved through the aperture instead of the conventional edge coupling, so that the bandpass filter is reduced less than half in size compared to conventional planar type. The resulting filter configuration has a near two-fold symmetry, where the aperture coupling is used in the middle of the coupling stages. We designed a bandpass filter using two tapped hairpin resonators, of which the order becomes four. The designed bandpass filter has the size of 8.9×18.3 mm. It has the return loss better than 17 dB and the insertion loss of less than 5 dB in overall passband. The measured results show good agreements with simulated ones.

Key words : Aperture Coupling, Bandpass Filter, Hairpin Resonator, Size Reduction.

Ⅰ. Introduction

Recent mobile communication terminals require such bandpass filters that have the compactness in size, the good selectivity and the low insertion loss. First, to meet the requirement in size, several type of planar filters, such as hairpin resonator filters, open loop resonator filters, and stepped-impedance resonator filters have been proposed[1]~[3]. The other way to reduce the size is to use dual mode resonators[4],[5]. Using dual mode resonators, the number of resonators for n-degree filter is reduced by half, so we can reduce the filter size in half. Next, to enhance the selectivity, bandpass filters with a pair of transmission zeros are frequently used. There are several bandpass filters using cross-coupling to improve its selectivity[6],[7]. Cross-coupling between non-adjacent resonators makes a pair of transmission zeros which can improve the filter selectivity. However, these filters are still quite large to be used in portable terminals. To overcome such problems, various bandpass filter designs based on the multilayer configurations have been performed[8],[9].

In this letter, we present a compact size aperture-coupled multilayer hairpin bandpass filter. This filter consists of two tapped hairpin resonators which have the good selectivity as well as the low insertion loss[10]. Each tapped hairpin resonator is a dual mode resonator and the tap can make a transmission zero either on lower side or upper side of a pass band according its electrical length. For this characteristic of the resonator we used, we could improve the selectivity. Also, we used aperture coupling to reduce the filter size in half. The proposed bandpass filter- has four-pole response but its size is almost same as one-pole hairpin filter. We will describe the design procedures and also demonstrate the measured performances of the filter.

Ⅱ. Analysis and Design Procedure

2-1 Hairpin Dual Mode Resonator

The proposed filter is composed of two tapped hairpin resonators which have dual mode characteristic. The structure of the two pole bandpass filter is presented in Fig 1[10]. The dual mode resonator is composed of two microstrip quarter-wavelength resonators and a tapped open stub. The quarter-wave length need not be shorted to ground, because the tapped open stub replaces the stub shorted to the ground. The tapped open stub has several important properties. It works as a K-inverter between the quarter-wavelength resonators. Also, by changing the length of a tapped open stub, one can control the notch frequency in the stopband. As the characteristic impedance Z_2 increases, the attenuation pole is located closer to the passband edge.

The characteristic impedances Z_1 and Z_2 of the resonator and the open stub inverter, respectively, are selected by location of the attenuation pole as well as the filter band width, because the value of inverter is defined by the characteristic impedances as well as the length of the stub, and the frequency of attenuation pole is defined by electrical length of the stub.

2-2 Filter Design

Fig. 2 shows the two layer structure of the aperture-coupled filter we propose. The tapped hairpin resonators on the top layer as well as on the bottom layer are

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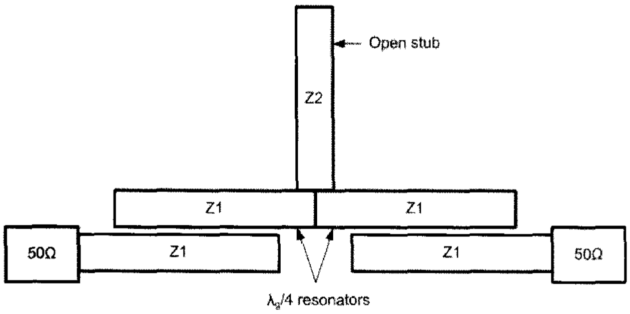
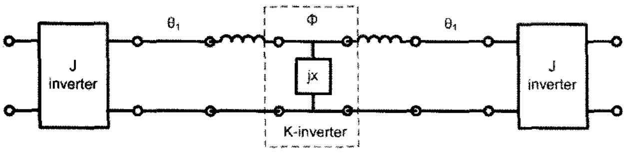
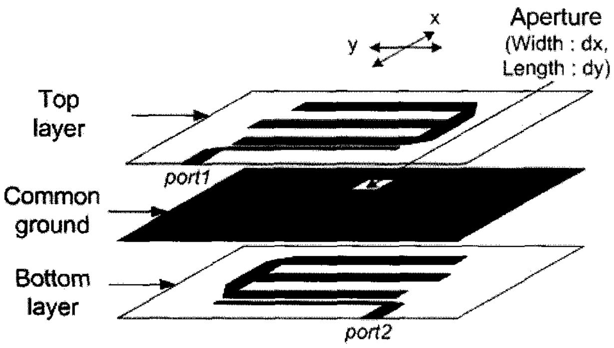


(a)

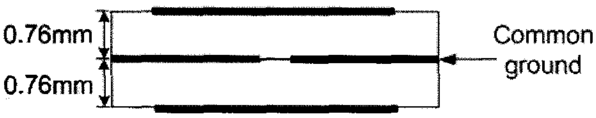


(b)

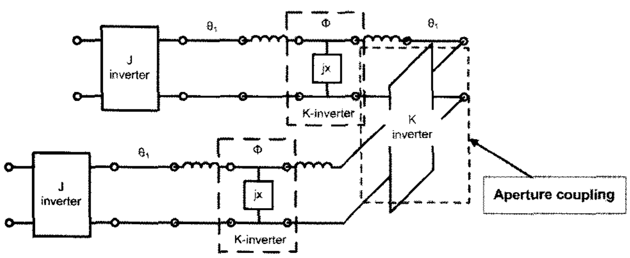
Fig. 1. (a) The structure of two pole bandpass filter using dual mode hairpin resonator and (b) its equivalent circuit.



(a) 3-D configuration



(b) Cross-sectional view of the filter



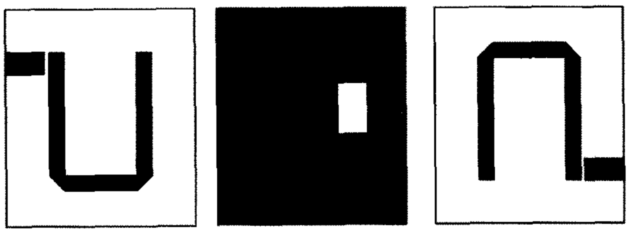
(c) Equivalent circuit

Fig. 2. The proposed aperture-coupled hairpin bandpass filter.

coupled through an aperture on common ground plane. The amount of coupling can be controlled by changing the dimension of the aperture. The coupling coefficients through the aperture can be derived based on full-wave analysis method[11]. Or we can also calculate them by varying its dimension, using the commercial software such as HFSS. When designing a aperture-coupled dual mode filter, there is a difficult to extract coupling coefficient between two dual mode resonator because four resonant peaks appear between two dual mode resonators. Usually, we can extract coupling coefficient between two normal resonators using the relation between two resonant peaks but we can not apply this formulation to the case of dual mode resonators. We can change the amount of coupling by varying the dimension of aperture but it is very difficult to find the right dimension because there are two variables, one is width and the other is length. So, first, we design a planar 2-stage four pole filter using dual mode hairpin resonators. Next, we can extract coupling coefficient between the two resonators which have same distance with the two dual mode resonators in the 2-stage planar filter but have no tap. Then we find the dimension of the aperture which has the same amount of coupling between two hairpin resonators without tap by simulation. By these experimental methods, we could determine the aperture size of the filter. In Fig. 3, the layout for extracting coupling coefficients of the aperture coupling is shown. In Fig. 4, several frequency responses of aperture-coupled tapped hairpin resonators are shown, there are two resonant peaks with corresponding frequencies f_1 and f_2, where f_1 is a lower peak frequency and f_2 is an upper one between two resonant peaks. The coupling coefficient K_{ij} is evaluated from the following relation[12].

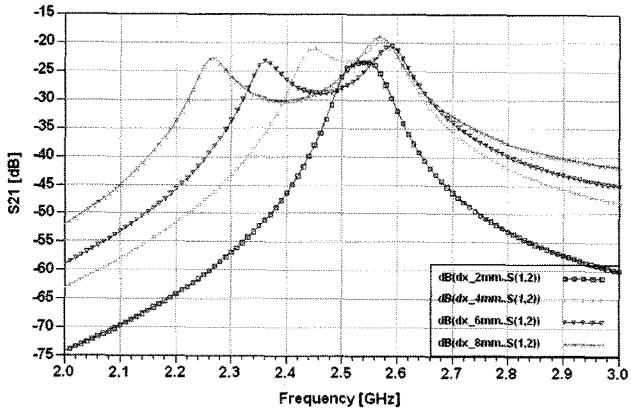
$$K_{ij}=\frac{f_2^2-f_1^2}{f_2^2+f_1^2} \tag{1}$$

We can decide the characteristic of coupling by investigating the phase of the coupling. If the phase of the coupling is negative, it is electric coupling, and the other case is magnetic coupling. In Fig. 5, the phase of the coupling of typical aperture size is presented. We

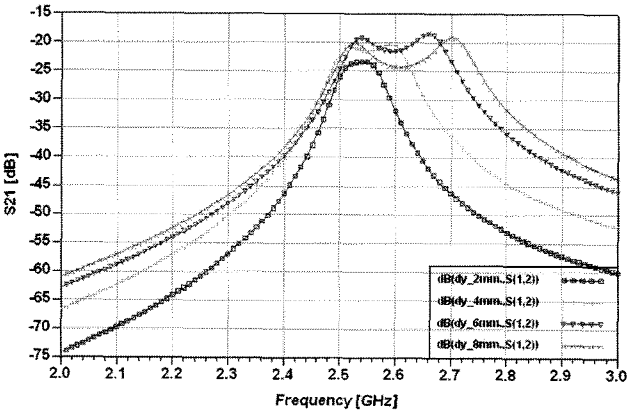


(a) Top layer (b) Common ground (c) Bottom layer

Fig. 3. The structure for extracting the coupling coefficient of the aperture coupling.

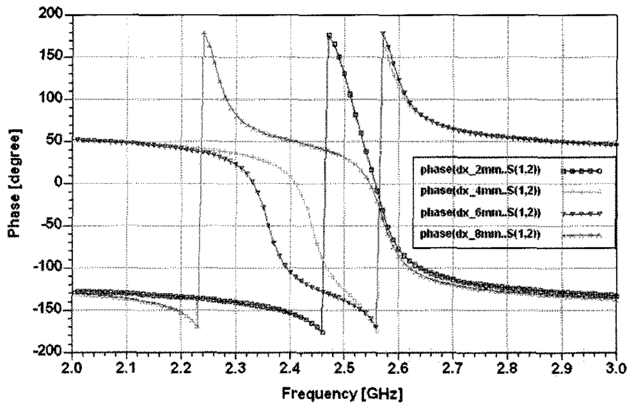


(a) With varying d_x(d_y=2 mm, fixed)

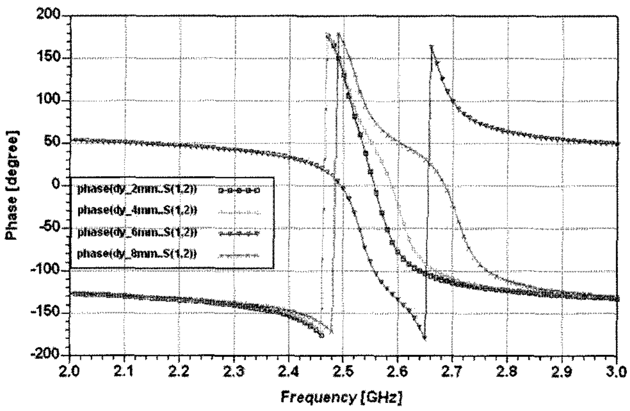


(b) With varying d_y(dx=2 mm, fixed)

Fig. 4. Typical resonant frequency responses of aperture-coupled hairpin resonators.



(a) With varying d_x(d_y=2 mm, fixed)



(b) With varying d_y(d_x=2 mm, fixed)

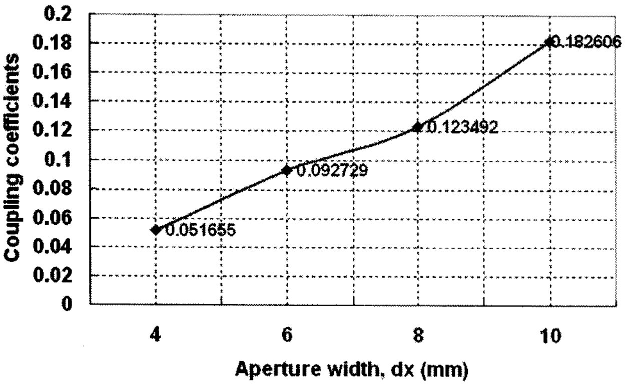
Fig. 5. Typical phase responses of aperture-coupled hairpin resonators.

can see some transitions between electric coupling and magnetic coupling, while the aperture size is changing. In Fig. 6, the graphs of the varying coupling coefficients are demonstrated. We chose the tapped hairpin resonator because of its compact size, good selectivity and low insertion loss. Its open stub not only makes attenuation pole for good selectivity but also works as a *K*-inverter between the quarter-wavelength resonators. Thus, a direct coupling is possible through the *K*-inverter and low insertion loss can be obtained. We can control the location of the attenuation pole by changing the length of the open stub. When designing 2-stage filter, we inserted two attenuation poles at lower and upper side of the pass band with two different lengths of open stubs.

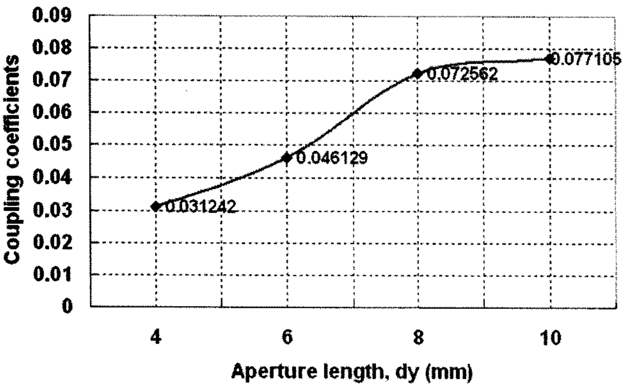
Its size is almost as same as one pole hairpin filter but it has fourth-order characteristics with better selectivity than other planar configurations. This filter offers more than 50 % size reduction over a single layer implementation.

Ⅲ. Measurement Performance

Several experimental bandpass filters were designed and tested. The final dimension of the aperture is 3×3.9 mm^2. The coupling coefficient corresponding to the aperture size is 0.995. The center frequency and the fractional bandwidth of the simulation result are 2.65 GHz and 7.5 %, respectively, and the center frequency and the fractional bandwidth of the measured result are 2.66 GHz and 7.5 % which is quite good agreement. The dimension of the filter is presented in detail in Fig. 7. The substrate has the thickness of 0.76 mm for each layer and the relative dielectric constant of 4.3. We used the simulators, Agilent's ADS as well as HFSS, to perform the fine tuning in order to obtain better performances. The simulated results as well as the measured ones are plotted in Fig. 8 where a very good agreement between two results is observed. In Fig. 8, the edge coupled planar filter is the structure in [10]. The simulated results of the proposed filter show almost the same responses as the conventional edge coupled planar filter although its size is reduced by half. The insertion loss of the measured result is 4.1 dB at the center frequency and less than 5 dB in overall passband and the return loss is better than 17 dB in the passband.

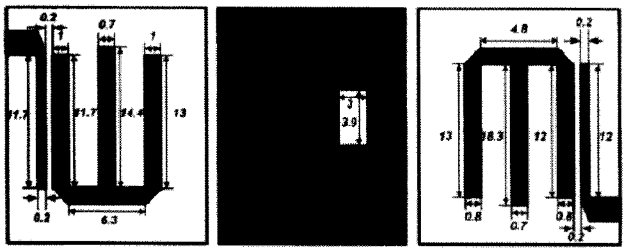


(a) With varying d_x(d_y=2 mm, fixed)



(b) With varying d_y(d_x=2 mm, fixed)

Fig. 6. Typical coupling coefficients for various aperture sizes.



(a) Top layer (b) Common ground (c) Bottom layer

Fig. 7. Dimension of the proposed filter.

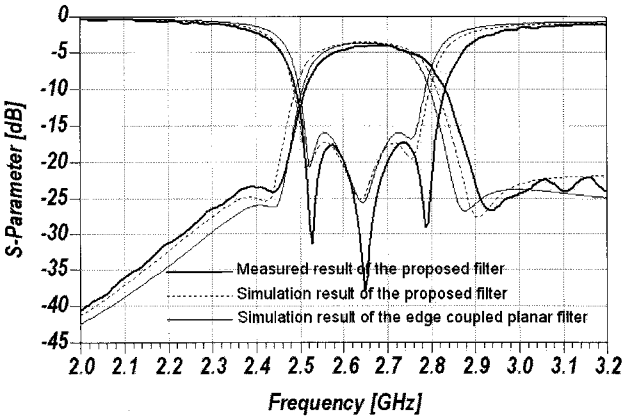


Fig. 8. Simulated and measured performances of proposed bandpass filter.

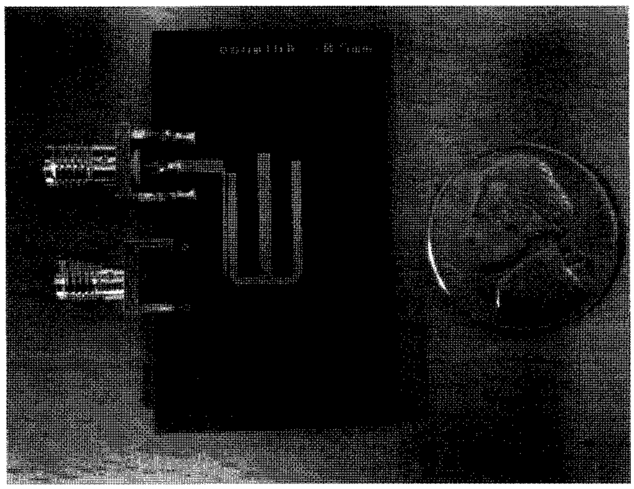


Fig. 9. Photograph of the proposed bandpass filter.

Ⅳ. Conclusion

In this paper, we presented an aperture-coupled tapped hairpin bandpass filter, in which we can achieve a 50 % size reduction. Some typical coupling coefficients through aperture were calculated using full-wave EM simulator HFSS for the design of the proposed filter. The performances of the proposed filter are as good as those of conventional planar bandpass filter. The proposed filter is compact in size 8.9×18.3 (mm) and also has a good selectivity with two transmission zeros. Its center frequency is 2.66 GHz and has 7.5 % fractional bandwidth. The insertion loss of the filter is 4.1 dB at the center frequency and less than 5 dB in overall passband, and the return loss is better than 17 dB in the passband. The measurement results show a good agreement with the simulated ones. Furthermore, by vertical stacking process, we can easily build the higher order bandpass filters.

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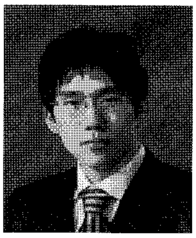

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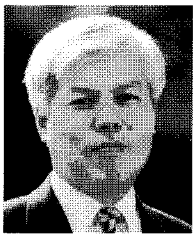

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