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DESIGN OF MINIATURE PLANAR DUAL-BAND FILTER WITH 0° FEED STRUCTURES

W. Xue, C.-H. Liang, X.-W. Dai, and J.-W. Fan

National Key Laboratory of Antennas and Microwave Technology
Xidian University
Xi'an, Shaanxi, China

Abstract—A novel dual-band planar filter is proposed in this paper. It is shown that the two transmission bands can be excited and designed using proposed resonators which combine different sizes of open-loop resonators. The main resonators control the low-band resonant frequency and the sub resonators control the high-band resonant frequency. With 0° feed structures added, the frequency selectivity of the filter is greatly improved. And the proposed filter also has advantages as low insertion loss and miniature size. The measurement of the filter is in good agreement with the simulation.

1. INTRODUCTION

Dual-band bandpass filters have gained great attention in wireless communication systems recently [1–5]. The traditional design methods of dual-band filters are realized by connecting two filter circuits with two different passbands [1] or making use of the basic topology of a stopband filter [2, 9]. However, these solutions suffer from high insertion loss and large overall size. Therefore, the importance of keeping filter structures to a minimum size and weight, low insertion loss, high frequency selectivity has been widely recognized [10–14].

In this paper, a novel structure using embedded resonators are designed to generate dual-band response. The main resonators control the low-band resonant frequency and the sub resonators control the high-band resonant frequency. The sub resonators are embedded into the main resonators, which makes the filter compact in overall size. 0° feed structures [6] are realized at both the lower and upper bands to generate additional transmission zeros. The proposed filter shows advantages as low insertion loss, compact size and high selectivity.

Details of filter design are presented and measured results are given to demonstrate the performance of the dual-band filter.

2. 0° FEDD STRUCTURE

Open-loop resonators have been employed as blocks of microstrip filters. There are several types of coupling for building filters, including electric coupling, magnetic coupling and mixed coupling. For electric coupling structure, a conventional feed structure is shown in Fig. 1(a). The electric delays of the lower and upper paths are different at the fundamental resonant frequency of the split-ring. This symmetric feed structure is referred to as a non-0° feed structure. While another feed structure called 0° feed structure is shown in Fig. 1(b), which has a 0° difference between the electric delays of the lower and upper paths.

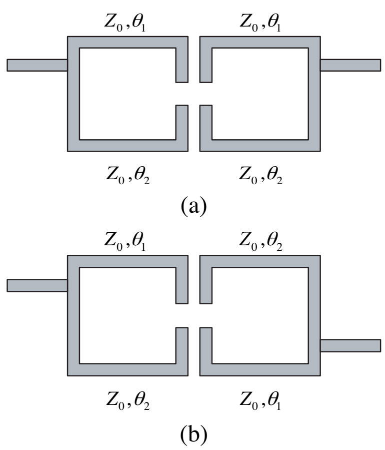

Figure 1. (a) Non-0° feed structure. (b) 0° feed structure.

The transmission matrices of the lower and upper signal paths in a 0 feed structure are found in (1) and (2), where $Y_0 = 1/Z_0$ and C_m is the coupling capacitance between the upper and the lower path, and is usually very small.

$$\begin{bmatrix} A_l & B_l \\ C_l & D_l \end{bmatrix} = \begin{bmatrix} \cos(\theta_1+\theta_2) + \dfrac{Y_0}{\omega C_m}\cos\theta_1 \sin\theta_2 & jZ_0 \sin(\theta_1+\theta_2) - j\dfrac{\cos\theta_1 \cos\theta_2}{\omega C_m} \\ jY_0 \sin(\theta_1+\theta_2) + j\dfrac{Y_0^2}{\omega C_m}\sin\theta_1 \sin\theta_2 & \cos(\theta_1+\theta_2) + \dfrac{Y_0}{\omega C_m}\sin\theta_1 \cos\theta_2 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} A_u & B_u \\ C_u & D_u \end{bmatrix} =$$
$$\begin{bmatrix} \cos(\theta_1+\theta_2)+\dfrac{Y_0}{\omega C_m}\sin\theta_1\cos\theta_2 & jZ_0\sin(\theta_1+\theta_2)-j\dfrac{\cos\theta_1\cos\theta_2}{\omega C_m} \\ jY_0\sin(\theta_1+\theta_2)+j\dfrac{Y_0^2}{\omega C_m}\sin\theta_1\sin\theta_2 & \cos(\theta_1+\theta_2)+\dfrac{Y_0}{\omega C_m}\cos\theta_1\sin\theta_2 \end{bmatrix} \tag{2}$$

the transmission matrix of the whole circuit can be written as (3)

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} =$$
$$\begin{bmatrix} \dfrac{A_uB_l+A_lB_u}{B_u+B_l} & \dfrac{B_uB_l}{B_u+B_l} \\ \dfrac{[A_uB_l+A_lB_u][B_uD_l+B_lD_u]-(B_u+B_l)^2}{(B_u+B_l)B_uB_l} & \dfrac{B_uD_l+B_lD_u}{B_u+B_l} \end{bmatrix} \tag{3}$$

From (1) and (2), it is clear that $A_u + A_l = D_u + D_l$, $B_u = B_l$ and $C_u = C_l$. The transmission matrix of a 0° feed structure can then be simplified as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \dfrac{A_u+A_l}{2} & \dfrac{B_u}{2} \\ \dfrac{(A_u+A_l)^2-4}{2B_u} & \dfrac{A_u+A_l}{2} \end{bmatrix} \tag{4}$$

the transmission coefficient can be found as

$$S_{21} = \frac{4B_uZ_L}{B_u^2+2(A_u+A_l)B_uZ_L+[(A_u+A_l)^2-4]Z_l^2} \tag{5}$$

The advantage of the 0° feed structure is that a pair of transmission zeros in the stopbands are realized to improve the selectivity of the filter. At the frequencies where transmission zeros exist, $S_{21} = 0$. To fulfill the condition, the necessary and sufficient condition for the existence of the transmission zeros is $B_u = 0$ and the denominator of (5) is not equal to zero. If $B_u = 0$, it is found that

$$\tan\theta_1 + \tan\theta_2 = 1/Z_0\omega C_m \tag{6}$$

Under a 0° feed structure, θ_1 is generally different from θ_2 to get the desired external quality factor. Then (6) can be simplified as

$$\tan\theta_1 \approx 1/Z_0\omega C_m \tag{7}$$

or

$$\tan\theta_2 \approx 1/Z_0\omega C_m \tag{8}$$

The transmission zeros occurs at the frequencies when $\theta_1 \approx \pi/2$ or $\theta_2 \approx \pi/2$.

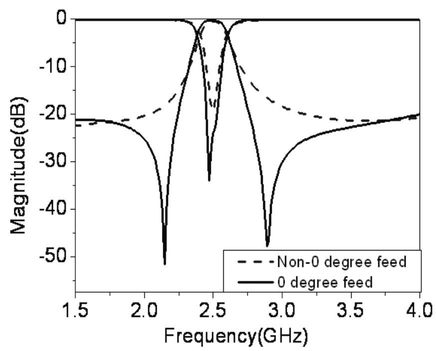

Figure 2. Simulated results with non-0° and 0° feed structures.

Fig. 2 is the comparison of the circuits with two different feed structures at the center frequency 2.5 GHz. The result proves that the analysis above is basically correct. When 0° feed structure is applied, $\theta_1 = 77.8°$ and $\theta_2 = 102.2°$ at the center frequency 2.5 GHz. Two zeros are obtained at 2.89 GHz and 2.20 GHz, when θ_1 and θ_2 approach $\pi/2$ respectively, the stopband rejection is greatly increased.

3. FILTER DESIGN

Fig. 3 presents the layout of the proposed dual-band filter. The proposed dual-band filter is composed of folded open loop half-wavelength resonators and stepped impedance structures. Dual-band operation can be achieved using embedded structure. The Embedded resonators are applied to generate the upper band, meanwhile, they are parts of the main resonators which control the lower passband. Both the main resonators and the embedded resonators are designed to be stepped impedance resonators (SIRs) to reduce the length of the transmission-line resonators. The coupling between the main resonators and the embedded resonators is electric coupling. The 0° feed structures are used to feed both the main resonators and the embedded resonators. There are two transmission zeros realized out of each passband and the selectivity of the filter is significantly improved.

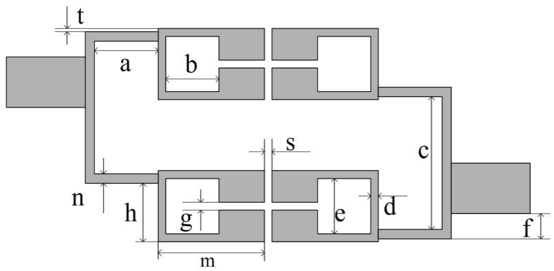

Figure 3. Layout of the proposed dual-band filter. Dimensions: $a = 3.3\,\mathrm{mm}$, $b = e = 3\,\mathrm{mm}$, $c = 8.5\,\mathrm{mm}$, $d = 0.5\,\mathrm{mm}$, $f = 1.5\,\mathrm{mm}$, $g = 0.6\,\mathrm{mm}$, $h = 3.4\,\mathrm{mm}$, $m = 6.5\,\mathrm{mm}$, $n = 0.5\,\mathrm{mm}$, $s = 0.7\,\mathrm{mm}$, $t = 0.1\,\mathrm{mm}$.

4. FABRICATED FILTERS AND MEASURED RESULTS

The filter is designed on a substrate with a thickness $h = 1\,\mathrm{mm}$ and a dielectric constant $\varepsilon_r = 2.65$. The dimensions are presented in Fig. 3. The center frequencies of the two passbands are designed at 2.4 GHz and 5.2 GHz.

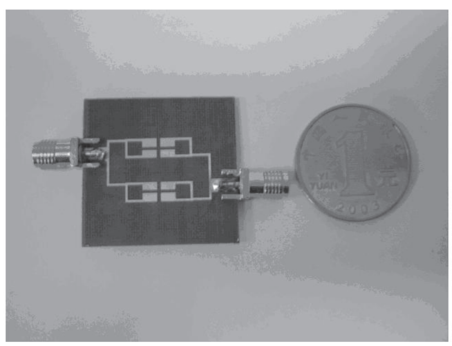

Figure 4. Photograph of the fabricated dual-band filter.

Fig. 4 shows the photograph of the fabricated filter. The simulated and measured results are presented and compared in Fig. 5. There are two transmission zeros out of each passband. The locations of the zeros are at 2.17 GHz, 2.69 GHz, 4.76 GHz and 5.69 GHz. The selectivity of the filter is significantly improved. The insertion loss is mainly due to the conductor loss. The measured results show good agreement with the simulation at both of the two passbands. The proposed filter can be used for WLAN application.

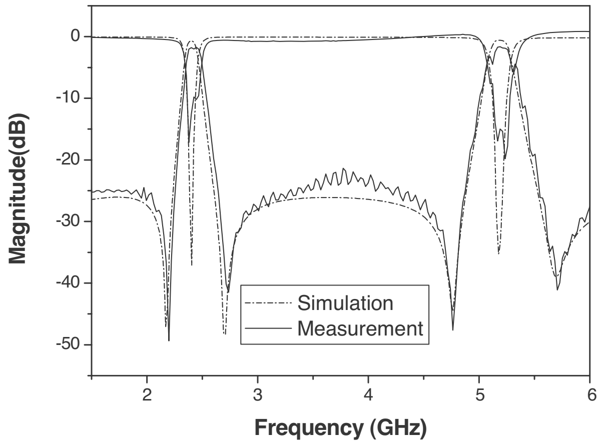

Figure 5. Simulated and measured results of the proposed dual-band filter.

5. CONCLUSION

A novel dual-band microstrip bandpass filter is proposed and constructed by using embedded resonators with 0° feed structure. After the descriptions of 0° feed structure, the filter is designed, fabricated and measured, which is not only compact in size, but also has advantages of low loss and improved selectivity. The good agreement between simulated and measured results validates the proposed structure.

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