Novel Compact Dual-band Bandpass Filter With Multiple Transmission Zeros and Good Selectivity

MinhTan Doan[1,2], Wenquan Che[1] and Wenjie Feng[1]

1. Department of Communication Engineering Nanjing University of Science & Technology
210094 Nanjing, China.
2. Department of Radio Electronic Engineering Le Qui Don Technical University, Hanoi, Vietnam.

E-mail: yeeren_che@yahoo.com.cn, doanminhtanhv@ yahoo.com

Abstract—**A novel compact microstrip dual-band bandpass filter (BPF) using short-stub loaded half-wavelength resonator with multiple transmission zeros and good selectivity is proposed in this letter. The characteristics of the dual-mode resonator are investigated by using even-odd mode analysis. To improve filter selectivity, a new structure of hook feed line of couple-line is introduced to produce six transmission zeros at the adjacent two passbands. A prototype of dual-band bandpass filter for WLAN (2.4 GHz) and WiMAX (3.5 GHz) applications is designed and fabricated for demonstration. Good agreement is observed between the measured and the theoretical expectation.**

Index Terms— **Dual-band bandpass filter, short-stub loaded half-wavelength resonator, multiple transmission zeros, fractional bandwidth.**

I. INTRODUCTION

The increasing demands for dual-band applications in modern wireless system such as the global systems for mobile communications (GSM) at 0.9/1.8 GHz, (WiMAX) 3.5 GHz, and wireless local area networks (WLANs) at 2.4/5.2 GHz microwave communication system. Planar microstrip dual-band bandpass filters have been receiving much attention due to the advantages such as small size, low cost, easy fabrication. Several schemes have been developed in [1]-[9]. The dual-band BPF can be constructed using stepped impedance resonators (SIRs), such as the ones in [1]-[3], although these structures are relatively complicated due to resonant frequencies of SIR are dependent, the three passbands at any desired frequencies can be obtained. In [4], a novel switchable bandpass filter with two-state frequency responses was presented, dual-band bandpass and single bandpass characteristics can be conveniently switched by turning pin diodes on and off. In [5], a dual-band filter was implemented by E-type resonators combining pseudo-interdigital coupling structure. Although the passband frequencies can be easily adjusted to desirable values, but the selectivity needs to be improved. To solve this problem, dual-band filter with multiple transmission zeros has been proposed in [6]-[10]. In [6], dual-band BPF using dual-feeding structure and embedded resonator was presented; dual-band BPF using parallel short-ended feed scheme was proposed in [7], and dual-band coupling and feed structures were proposed to fulfill the requirements of both passband frequencies and bandwidths in [8]. The two desired frequencies can be conveniently controlled by tuning the lengths of two sets quarter-wavelength resonators [9], dual-mode resonators, i.e., crossed open-short stub loaded resonator and tri-section stepped impedance resonator [10]. In these structures, four transmission zeros near the edges of the passbands are employed to achieve good selectivity.

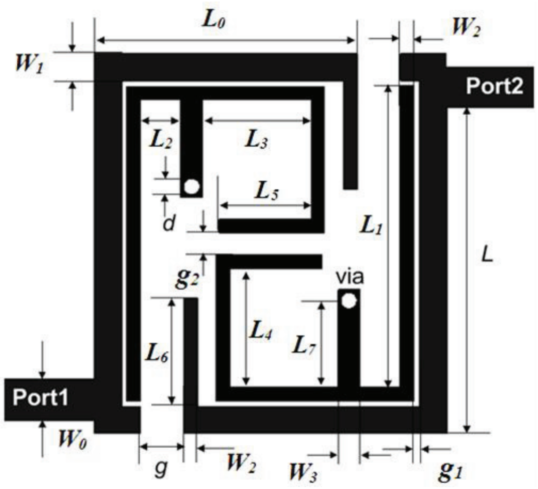

Fig. 1 Layout of the proposed dual-band bandpass filter.

In this work, a novel compact microstrip dual-band bandpass filter with six transmission zeros to improve selectivity is presented. Four transmission zeros near the edges of the passband are employed to achieve high selectivity. Meanwhile, good lower and upper stopband are achieved by another transmission zeros. Moreover, the center frequencies of dual-band filter can be independently controlled to desired values by tuning the dimensions of the short-stub loaded half-wavelength resonator. The theoretical design, simulation and experimental results are given and discussed.

II. ANALYSIS AND DESIGN OF PROPOSED FILTER

Fig. 1 shows the layout of proposed dual-band BPF with the outer set is hook feed lines structure utilizing stepped-

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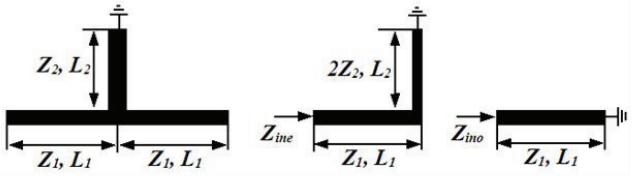

(a) (b) (c)

Fig. 2 Short -stub loaded half-wavelength resonator. (a) Dual-mode with short-circuited stub, (b) Even-mode equivalent circuit, (c) Odd-mode equivalent

impedance coupling. Two microstrip lines with characteristic impedance of 50 ohm are directly connected, as output and input ports. The inner resonator is short-stub loaded half-wavelength resonator. It consists of two identical half-wavelength resonators and short-stub in the midpoint. The two short-stub loaded half-wavelength resonators and two feed line are folded symmetrically. It is constructed on a dielectric substrate with $\varepsilon_r = 4.4$ and thickness of $h = 0.8$ mm.

A. Characteristic of the Dual- mode Resonators

Fig. 2 shows the conventional short-stub loaded half-wavelength resonator, Z_1, L_1 and Z_2, L_2 are the characteristic impedance and length of the half wavelength line and the short-stub, respectively. The resonator is symmetrical and odd-and even-mode analysis can thus be used for characterization. The input impedance for even- and odd-mode can be expressed as

$$Z_{ine} = jZ_1 \frac{Z_1 \tan(\beta L_1) + 2Z_2 \tan(\beta L_2)}{Z_1 - 2Z_2 \tan(\beta L_1) \tan(\beta L_2)} \tag{1}$$

$$Z_{ino} = -jZ_1 \cot(\beta L_1) \tag{2}$$

Where β is the propagation constant, and it is equal for even-mode and odd-mode. The resonance condition is

$$Z_{ine} \to \infty, \quad Z_{ino} \to \infty \tag{3}$$

The fundamental resonant frequency can be determined as follows:

$$f_{even} = \frac{c}{4(L_1 + L_2)\sqrt{\varepsilon_{eff}}} \tag{4}$$

$$f_{odd} = \frac{c}{4L_1\sqrt{\varepsilon_{eff}}} \tag{5}$$

While c is the light speed in free space, ε_{eff} the effective dielectric constant of the substrate.

From (4) and (5), indicate that two center frequencies can be easily adjusted to the desired value by tuning the length of short-stub and half-wavelength line, as its width is kept unchanged.

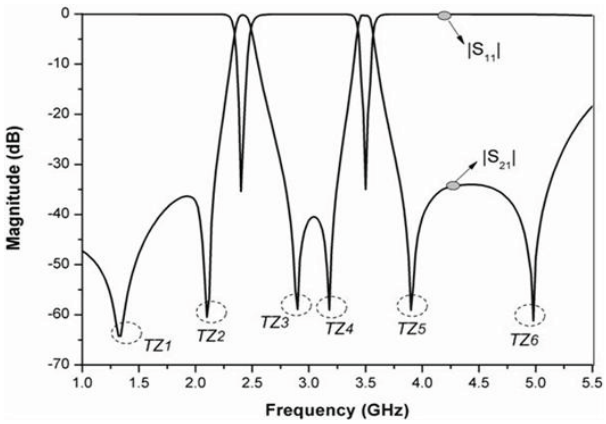

Fig. 3 Simulated frequency response S parameters of filter with six transmission zeros

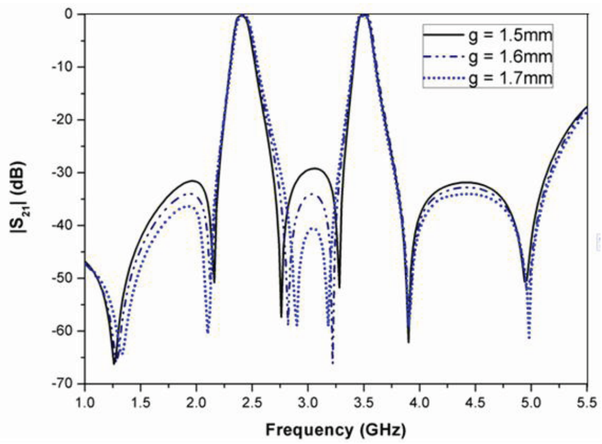

Fig. 4 Simulated frequency response S_{21} parameters of filter under different values of g

B. Design of proposed filter

Equation (4) is based on the special case of $Z_1 = 2Z_2$. From (4)-(5), when $L_2 > 0$, we can obtain $f_{\text{even}} < f_{\text{odd}}$. So, in this design, the odd-mode resonant frequency f_{odd} is 3.5 GHz, and the even-mode resonant frequency f_{even} is 2.4 GHz. From (4), we can see that the first resonance frequency, namely f_1, can be controlled by the ratio of the characteristic impendence and electrical length of the half wavelength line and the short-circuited stub. Meanwhile, from (5), the second resonance frequency, namely f_2 can be dominated by adjusting the electrical length of the half- wavelength line. As analyzed in [5], the voltage at the half-wavelength line center is zero at f_1. Hence, no signals at this frequency point can be delivered to the short-stub due to no effect on the coupling strength at f_1.

In addition, to improve the selectivity of filter, the modification skew-symmetrical 0^0 feeding structure [12] is introduced to achieve extra transmission zeros in the stopband, as shown in Fig. 1. The simulated frequency response of proposed dual-band filter is shown in Fig. 3, in which six transmission zeros can be observed at the adjacent two

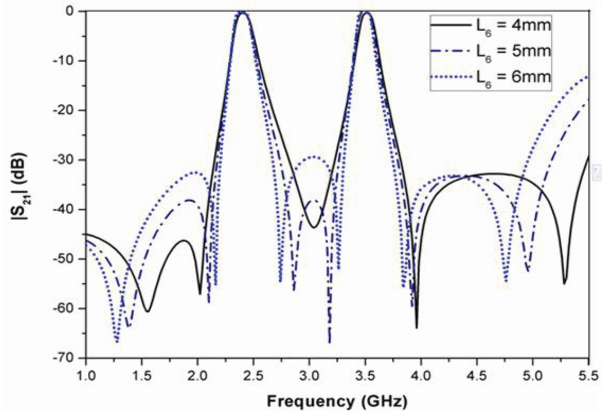

Fig. 5 Simulated frequency response S_{21} parameters of filter under different values of L_6

passbands. Six transmission zeros are finely allocated and can be adjusted by the dimensions of the structures mentioned above. Four transmission zeros near the edges of the passbands, saying, TZ_2 to TZ_5, are produced to achieve good selectivity. Meanwhile, good lower and upper stopband is achieved by another transmission zeros TZ_1 and TZ_6. When the width, length of the feed line and the coupling spacing g_1 are fixed (g_1 = 0.2 mm), the coupling degree between the feed line and the resonator at two bands are determined only by length of g and L_6. The reason for adding stub with length of L_6 is to make it easy to achieve more tunable states of transmission zeros. Fig. 4, and Fig. 5 shows the simulated results of the proposed filter with different g and L_6. It is noted that all these transmission zeros will move close to their passbands with the decrease of g and L_6. However, with decreasing L_6 two transmission zeros TZ_1 and TZ_6 can be shifted within a wide range. Thus, stopband can be tuned.

A dual-band BPF with resonance frequencies at 2.4 GHz and 3.5 GHz is designed. It is constructed on a substrate with relative permittivity of 4.4 and thickness of h = 0.8 mm. The design parameters optimized by Ansoft HFSS 10.0 are given as follows: W_0 = 1.5 mm, W_1 = 1 mm, W_2 = 0.5 mm, W_3 = 0.8 mm, g = 1.6 mm, g_1 = 0.2 mm, g_2 = 0.8 mm, L = 12 mm, L_0 = 9.65 mm, L_1 = 11.1 mm, L_2 = 1.5 mm, L_3 = 4 mm, L_4 = 4.4 mm, L_5 = 3.4 mm, L_6 = 5 mm, L_7 = 3.2 mm, d = 0.5 mm. The designed dual-band BPF is compact with size of 30 mm x 30 mm. Fig. 7 illustrates the simulated frequency response, the resulting 3-dB fractional bandwidths (FBWs) for the two passbands centered at 2.4 GHz and 3.5 GHz are about 2.33-2.49 GHz (160MHz) 6.7%, and 3.42-3.57 GHz (150MHz) 4.3%, respectively.

III. MEASURED RESULTS AND DISCUSSIONS

A prototype is fabricated to demonstrate the design strategies, as shown in Fig. 6. The measurement is accomplished using Agilent 8753ES network analyzer. For comparison, the measured results and simulation results are shown together in Fig. 7. The first passband is centered at 2.4 GHz, with the 3 dB bandwidth of 6.7%, meeting the requirement of WLAN systems. The minimum insertion loss is measured to be 0.75 dB. The return loss within the passband is greater than 23 dB.

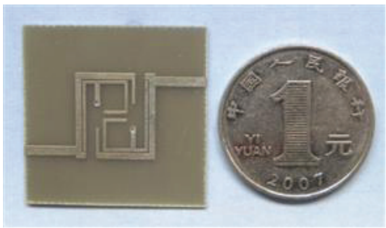

Fig. 6 Photograph of the fabricated dual-band BPF.

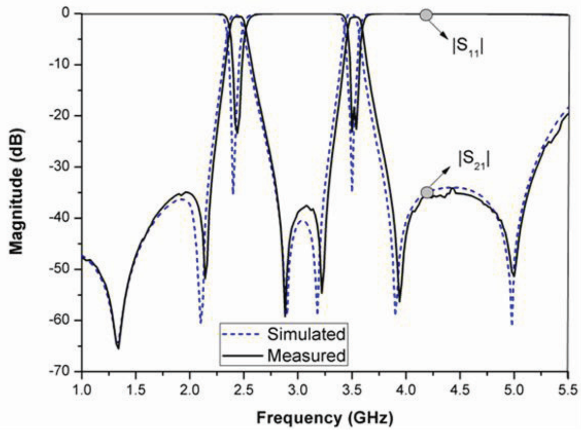

Fig. 7 Measured and simulated results of the dual-band BPF

The second passband is located at 3.5 GHz, meeting the application requirement of WiMAX. The 3 dB bandwidth is 4.3%. The minimum insertion loss is measured to be 0.85 dB. The return loss within the passband is greater than 20 dB.

Four transmission zeros are created at 2.11 (TZ_2), 2.85 (TZ_3), 3.19 (TZ_3) and 3.92 (TZ_4) GHz, which are near two passband edges and significantly enhance the roll-off skirts, meanwhile, good lower and upper stopband is achieved by another transmission zeros at 1.3 GHz (TZ_1), and 4.97 GHz (TZ_6). The stopband rejection is better than 33.5 dB in the whole two passbands.

IV. CONCLUSION

A novel compact dual-band BPF is proposed and designed, which is implemented with short-stub loaded half-wavelength resonator and new coupling structure. Two passbands for WLAN and WiMAX applications are presented. Four transmission zeros near the passband edges are introduced to achieve high selectivity. Meanwhile, good lower and upper stopband is achieved by another transmission zeros. Thus, the bandwidths of this filter are controllable, while taking good selectivity and improved lower-and upper-stopband performance. Good agreement is observed between the experiments and theoretical analysis, indicating the validity of the proposed design strategies.

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