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COMPACT DUAL-MODE TRI-BAND TRANSVERSAL MICROSTRIP BANDPASS FILTER

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Abstract—A novel microstrip dual-mode tri-band bandpass filter is presented. The filter consists of an open stub loaded dual-mode resonator and two short stub loaded dual-mode resonators. By utilizing the odd- and even-mode resonance properties of the proposed dual-mode resonators and the introduced source-load coupling (S-L coupling), the filter is designed with two transmission zeros at both sides of each passband, which will improve the selectivity of the filter. To validate the design theory, one 100 MHz 3 dB absolute equal bandwidths dual-mode tri-band filter with three passbands located at the centre frequencies of 1.8, 2.4 and 5.0 GHz, respectively, is designed and fabricated. Both experimental results agree well with the simulations.

1. INTRODUCTION

In modern wireless and mobile communication systems, the increasing demand of wireless communication applications necessitates RF transceivers operating in multiple separated frequency bands. For example, global systems for mobile communications (GSMs) operate at both 0.9 and 1.8 GHz. IEEE 802.11b and IEEE 802.11a wireless local area network (WLAN) products operate in the unlicensed industrial-scientific-medical (ISM) 2.4 and 5 GHz bands, respectively. Therefore, the multiband filter has been gaining wide attention in recent years. Dual-band filter is the most common multiband filter, which has been analyzed deeply in many literatures with various configurations [1–5]. Tri-band microstrip planar filters were reported [6–16]. The tri-band filters were reported in [6–8] using SIR. However, the filters have

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poor selectivity since there is no transmission zero at stopband. A stub loaded tri-band bandpass filter (BPF) was presented in [9, 10], which also had poor selectivity and a large area. The tri-band filter using assembled resonators was proposed in [11]. Tri-band bandpass filter based on a dual-plane microwave and DGS slot structure with improved band allocation was proposed in [12]. However, one common disadvantage for this structure having a defected pattern etched in the ground plane is that the whole structure must be suspended far from other ground conductors for the defected ground plane to be effective.

On the other hand, dual-mode filters are also attractive because each dual-mode resonator can be used as a doubly tuned resonant circuit. Thus, the number of resonators required for a given degree of filter is reduced to half, resulting in a compact filter configuration [17]. Therefore, dual-mode tri-band filters have received much attention.

The motivation of this letter is to design a high selectivity dual-mode tri-band bandpass filter based on three dual-mode transversal filters. For this purpose, the new filter is constructed by an open stub loaded dual-mode resonator and two short stub loaded dual-mode resonators. One 100 MHz 3 dB absolute equal bandwidth dual-mode tri-band filter, with three passbands located at the centre frequencies of 1.8, 2.4 and 5.0 GHz, respectively, is designed and fabricated.

2. DESIGN OF TRI-BAND DUAL-MODE FILTER

The layout of the proposed filter is shown in Fig. 1. It consists of two short stub loaded dual-mode resonators and an open stub loaded dual-mode resonator, i.e., resonator 1, resonator 2 and resonator 3. The short stub loaded dual-mode resonator is composed of a stepped impedance hairpin resonator loaded by a short stub in the centre. The open stub loaded dual-mode resonator is composed of a hairpin resonator loaded by an open stub in the centre. Resonator 1, resonator 2 and resonator 3 operate at 2.0 GHz, 2.4 GHz and 5.0 GHz, respectively. For a compact structure, the SIR hairpin resonator is used. The capacitive S-L coupling can be introduced by the gap So and So1.

Each dual-mode resonator is used to result in two non-degenerate modes, i.e., even and odd modes. We can change the even mode by adjusting the dimension of the loaded stub, whereas, the odd mode is unchangeable. The stub loaded dual-mode resonator has some very important properties. First, there are two main coupling paths between source and load. Second, for the dual-mode resonators, the two modes are not coupled to each other [18]. Thus, the stub loaded dual-mode filters are special two-order full canonical transversal filter. The two-

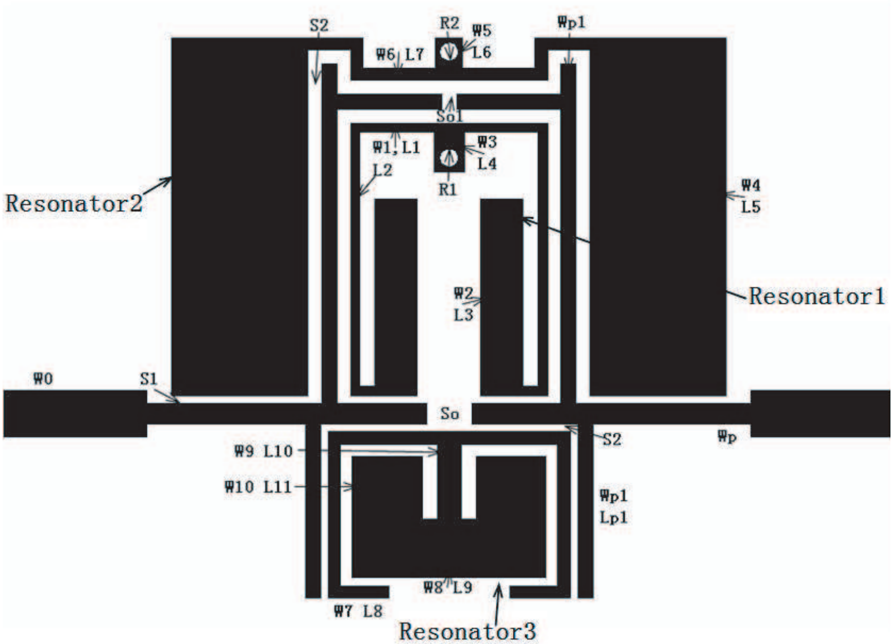

Figure 1. Layout of the proposed dual-mode tri-band filter.

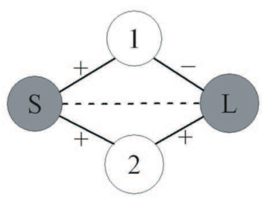

Figure 2. Corresponding coupling scheme of each resonator (1 and 2 represent the odd and even mode, respectively).

order full canonical transversal filter has an inherent transmission zero in stopband. By introducing S-L coupling, an additional transmission zero is created near passband [19, 20]. Furthermore, due to the intrinsic characteristics of transversal filter, the bandwidths of three bands can be regulated in a relatively wide range. The input/output feedline is utilized to couple with the three dual-mode resonators to realize tri-band response. Furthermore, the introduced S-L coupling can generate an additional transmission zero outside the each passband, which results in a high selectivity.

The corresponding coupling scheme for each resonator is shown in Fig. 2. The signal is coupled to each resonator at the same time, providing two main paths for the signal between the source and load, and no coupling between each mode is introduced. Therefore, full canonical transversal filter theory can illuminate the dual-mode resonator. In each band, a different resonator operates at an even and odd modes, respectively. The inherent transmission zero can be created near each band due to two main path signals counteraction, as explained in [18]. For the open stub loaded dual-mode resonator, the coupling matrix of each resonator can be written down as

$$\begin{bmatrix} 0 & M_{S1} & M_{S2} & M_{SL} \\ M_{S1} & M_{11} & 0 & M_{1L} \\ M_{S2} & 0 & M_{22} & M_{2L} \\ M_{SL} & M_{1L} & M_{2L} & 0 \end{bmatrix} \tag{1}$$

As illustrated in [18], the inherent transmission zero due to two main path signals counteraction can be provided in a low-pass prototype as follows:

$$\Omega_{inh} = \frac{M_{11}M_{S2}^2 - M_{22}M_{S1}^2}{M_{S1}^2 - M_{S2}^2} \tag{2}$$

Thus, the inherent transmission zero can be shifted from one side of the passband to the other by properly choosing the relative values of M_{S1} and M_{S2} as well as the signs of M_{11} and M_{22}. Therefore, we can obtain the inherent zero at lower stopband. For the short stub loaded resonator, the inherent zero is always at lower stopband. Three additional transmission zeros can be created at upper stopband of each band by introducing capacitive S-L coupling. Therefore, we can achieve two transmission zeros at both sides of passband, which can improve the selectivity. The design process is simple since there is no coupling among three resonators. We can design each band respectively by the coupling matrix without changing the other band response. The bandwidth of each passband can be adjusted by changing the length of loaded stub and the width ratio of hairpin resonator and stub of each resonator. Therefore, the bandwidth of passband can be easily adjusted.

3. SIMULATION AND MEASUREMENT RESULTS

A 1.8/2.4/5 GHz with 100 MHz 3 dB absolute equal bandwidths tri-band filter is designed to validate the concept. The coupling matrix is shown in Eq. (1). The substrate used here is Duroid 5880 ($\varepsilon_r = 2.2$, thickness $= 0.508$ mm). The final structure parameters of the bandpass filter are as follows: $W1 = 0.3$ mm, $W2 = 14$ mm, $W3 = 1$ mm,

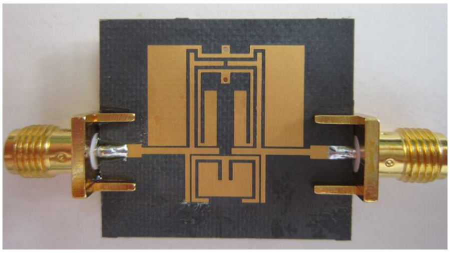

Figure 3. The photograph of the fabricated BPF.

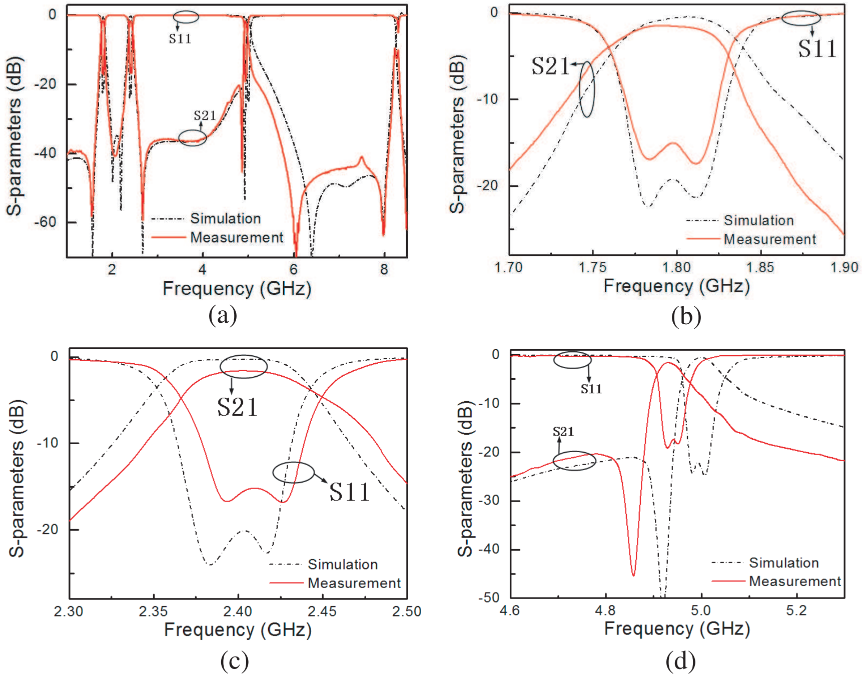

Figure 4. Measured and simulated frequency responses of filter. (a) Wideband response. (b) Narrowband response at 1.8 GHz. (c) Narrowband response at 2.4 GHz. (d) Narrowband response at 5 GHz.

$W4 = 4.5$ mm, $W5 = 0.9$ mm, $W6 = 0.4$ mm, $W7 = 0.4$ mm, $W8 = 1.9$ mm, $W9 = 2.1$ mm, $W10 = 2.1$ mm, $Wp = 0.7$ mm, $Wp1 = 0.5$ mm, $Wp2 = 0.5$ mm, $W0 = 1.53$ mm, $L1 = 2.75$ mm, $L2 = 9$ mm, $L3 = 6.5$ mm, $L4 = 1.3$ mm, $L5 = 11.8$ mm, $L6 = 1$ mm, $L7 = 2.4$ mm, $L8 = 2$ mm, $L10 = 2.5$ mm, $L11 = 2.3$ mm, $Lp1 = 5.75$ mm, $So = 1.5$ mm, $So1 = 0.5$ mm, $S1 = 0.25$ mm, $S2 = 0.46$ mm, $S3 = 0.25$ mm, $R1 = 0.3$ mm, $R2 = 0.3$ mm. The total area of the proposed filter is $18.34 \times 18.52\,\text{mm}^2$, which corresponds to a size of $0.15\lambda \times 0.15\lambda$, where λ is the guided wavelength at the center frequency 1.8 GHz. Thus, the proposed filter is very compact. Fig. 3 shows the photograph of the fabricated filter. Fig. 4 shows the simulated and measured results, which are in good agreement. There are two transmission poles inside each passband, which corresponds to the two resonance modes of each dual-mode resonator. The measured minimum insertion losses for the three passbands are 1.45, 1.9 and 1.7 dB, respectively. There exist two transmission zeros with a better than 35 dB suppression degree outside each passband, as expected. Furthermore, the spurious frequencies are suppressed from 5.1 GHz up to 8.1 GHz with a better than 20 dB suppression degree. There is a slight response discrepancy at 5 GHz between simulated and measured results. This phenomenon is due to resonant frequency shift of the resonators, which might owe to the variation of material characteristic in higher frequency range and manufacture effect. It can be rectified by slightly adjusting the dimensions of open stub loaded dual-mode resonator. Thus, the proposed filter is characterized with low insertion loss, compact size and high selectivity.

4. CONCLUSIONS

A microstrip dual-mode tri-band bandpass transversal filter is proposed. One sample filter with three passbands located at 1.8, 2.4 and 5 GHz has been designed and measured for demonstration. Results indicate that the proposed filter has the properties of compact size, low insertion loss and high selectivity. With all these good features, the proposed filter is applicable for modern wireless multiband communication systems.

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