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Compact Stepped Impedance Resonator Bandpass Filter with Tunable Transmission Zeros

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Abstract

This paper proposes a compact microstrip bandpass filter (BPF) with tunable transmission zero, narrow bandwidth and low insertion loss. Transmission zeros are the key to improve the band rejection and filter frequency selectivity. A λ/4 stepped impedance resonator (SIR) with two additional via holes has been adopted to obtain a compact size and a pair of transmission zero (TZ). The BPF is designed to operate at 3.5 GHz with fractional bandwidth (FBW) of 7.2%.Furthermore, three techniques have been developed to create a pair of controllable transmission zeros on both side of each passband. The TZ can be controlled by adjusting either magnetic or electric coupling. The measured return losses and insertion lossis larger than 18 dB and 2.2 dB respectively. The overall size of the proposed design filter is 5.3mm x 5.5mm without considering the feeding lines.

Keywords: *bandpass filter, transmission zero, SIR, Via Hole*

1. Introduction

Recently, there has been a tremendous increasing interest in microstrip filters due to the development of communication technology. Various filter designs have been proposed [1-8]. A communication system requires a bandpass filter with compact size, wide stopband, high selectivity and low insertion loss. An excellent upper-and lower-stopband performance is significantly demanded for a wideband and broadband BPF to suppress the unwanted interference or noise [1]. To provide these requirements, a BPF with a wide band rejection and transmission zero (TZs) should be included. Transmission zeros are the key to improve the band rejection and filter frequency selectivity. To obtain the TZs, some techniques have been done [2-5]. In general, the TZ can be obtained by using separate electric magnetic coupling (SEMC) technique [2], cross coupling [3], and mixed electromagnetic coupling [4]. The mixed electromagnetic coupling has been explained In [4]. A mixed electromagnetic coupling can be obtained by combining two coupled resonators with a maximum magnetic and electric fieldsfrom the open gap acurately. By tuning the gap distance between resonator, the coupling coefficient can be altered and the TZs can be introduced in both lower stopband and upper stopband. In SEMC, the magnetic and electric coupling is created in separated path. The magnetic coupling is introduced by adding via holes and the electric coupling is created by the resonator gap spacing. In [5], a triangular stepped impedance resonators with separate electric and magnetic coupling paths has been reported. The transmission zero can be obtained by both electric-dominant coupling and magnetic-dominant coupling.

In this paper, a miniaturized BPF operates at 3.5 GHz for WIMAX application with the FBW of 7.2% has been proposed. A λ/4 stepped impedance resonator (SIR) with two additional via holes has been adopted to obtain a compact size and a pair of TZ. This study provides a simple and effective method to design a low loss, wide rejection band and compact BPF with a tunable TZ without any complex topology design and fabrication process.

2. Design Procedure

Figure 1 shows the geometry of the proposed miniaturized BPF. In this figure, a second order resonator of the λ/4 SIR has been constructed using a FR-4 substrate with the thickness of 0.8 mm. These resonators are connected to the ground plane by means of via hole.

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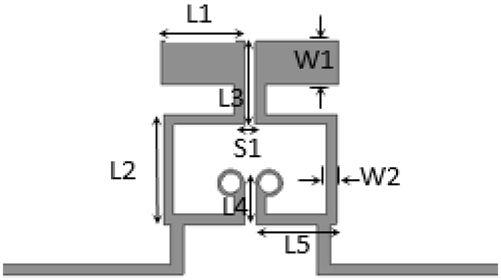

Figure 1. Structure of bandpass filter
(L1=2.5, L2=3.3, L3=2.5, L4=1.3, L5=2.5, W1=1.3, W2=0.3, S1=0.3. All are in mm)

The external quality factor *(Q_e)* and coupling coefficients *(k)* are the two most important parameters for a coupled resonator BPF design. To obtain Q_e, the proper tapped feed position *(P_t)* need to be tuned carefully. The coupling coefficient can be obtained as a function of the coupled gap distance *(S)* as shown in Figure 1. The coupling coefficient can be written as

$$K_{i,i+1} = \pm\frac{f_2^2-f_1^2}{f_2^2+f_1^2} \tag{1}$$

$$Q_e = \frac{\omega_0 \tau(\omega_0)}{4}\left(1-y_{in}^2(\omega_0)\right). \tag{2}$$

The external quality factor Q_e can be derived in terms of the input admittance y_{in} and the group delay τ_r that are obtained from the reflection coefficient and the derivative of its phase with respect to angular frequency, respectively.The values of k and Q_e are calculated according to

$$k_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \tag{3}$$

$$Q_e = \frac{g_1}{FBW} = \frac{g_n g_{n+1}}{FBW} \tag{4}$$

where FBW is the fractional bandwidth and g_i is the i_{th} prototype element value of a second-order 0.5 dB equal-ripple Chebyshev BPF. In this design, g_1=1.403, g_2=0.707, and g_3=1.984. Generally speaking, the coupling coefficient determines the fractional bandwidth of the passbands while the external quality factor specifies the tapped position of feed ports.

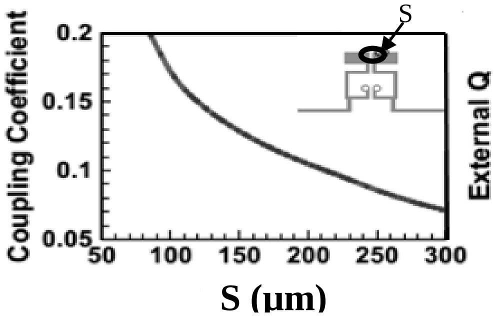

Figure 2. Spacing gap resonator versus coupling coefficient

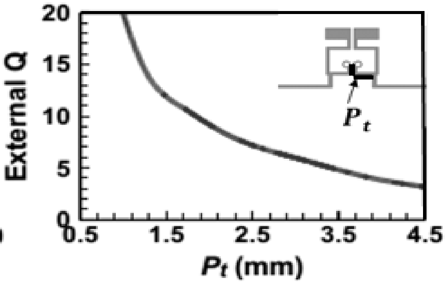

Figure 3. Tape position of the port versus the external quality factor

The desired coupling coefficients and external quality factors are obtained by adjusting the gap width between two resonators and the tapped position of the feedlines. Their values are: Q_{e1}=19.39 and k=0.072. It can be found from Figure 2 and Figure 3 that the coupling coefficientand external quality factor values correspond to a resonator gap spacing of S=300 μm and a tapped feed position of P_t=2.2 mm.

3. Result and Approach for Tunable Transmission Zeros

Figure 4 compares the magnitudes of S_{11} and S_{21} between simulation and measurement, indicating a good agreement over a frequency range up to 8 GHz. The measured return loss is larger than 18 dB. Moreover, the measuredinsertion loss is less than 2.2 dB. Two transmission zeros are located at 2.7 and 5.2 GHz respectively. As can be seen in figure1, Theoverall size of the proposed design filter is 5.3mmx5.5mm. Beside its compact size, this proposed design can realize a pair of transmission zero effectively.

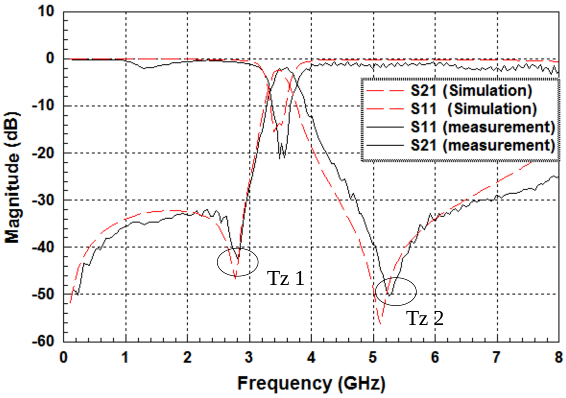

Figure 4. The simulation and measurement result

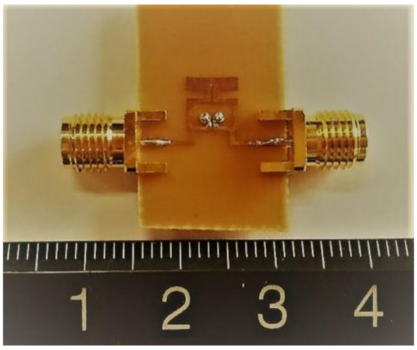

Figure 5. Photograph of fabricated filter

This paper also develops a novel approach to tune the TZs. There are 3 ways to tune the TZ in this BPF. The TZ can be tuned by adjusting the gap distance between resonator as shown in Figure 6. The Transmission zeros of the BPF can be controlled by adjusting the coupled gap distance *(S1)*, the width of the top resonator *(W1)*, and the length of the resonator's neck *(L3)* as depicted in Figure 1.

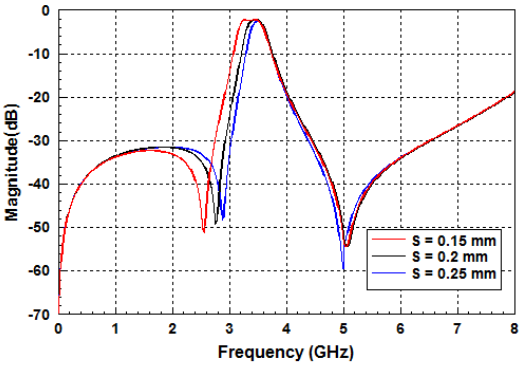

Figure 6. TZs shifting by the resonator spacing gap

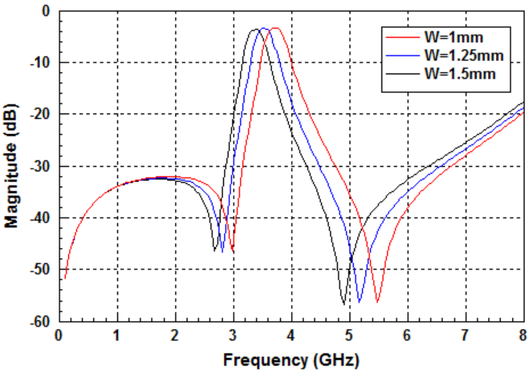

Figure 7. TZs shifting by the width of the top resonator

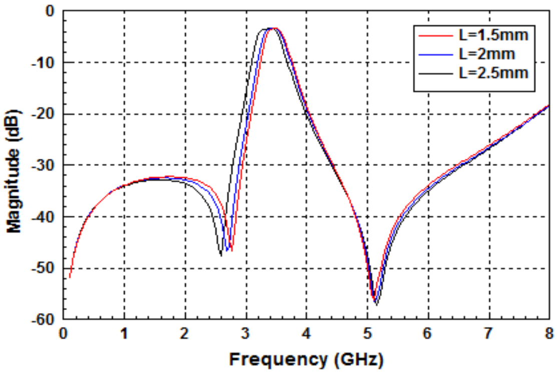

Figure 8. TZs shifting by the resonator’s neck length

According to Figure 6, when S increases, the first transmission zero moves largely to higher frequencies while the second transmission zero remains the same. Obviously, it makes the transmission zero frequencies closer to the passband, causing a higher roll-off rate for passband-to-stopband transition. Figure 7 shows how the top resonator width *(W1)* influences on the change of transmission-zero frequencies. It reveals that all the transmission zeros shift to higher frequencies as *W1* increases.Figure 8 shows the change of the transmission zero frequencies as a function of the resonator’s neck*L3*. As this *L3* longer, the first transmission zero shifts to higher frequency while keeping the second transmission zero.

4. Conclusion

In this paper, a prototype of a very compact Stepped Impedance Resonator with tunable transmission zeros has been proposed. A bandpass filter with the 3.5 GHz center frequency and FBW of 7.2% has been simulated and fabricated using the FR4 substrate. Moreover, a novel way to introduce transmission zeros are explained. The overall size of the proposed design filter is 4.2mm x 5.2mm without considering the feeding lines.

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