Microstrip Filters with Adjustable Transmission Zeros Using Inductive-coupled Open Stub-loaded Resonators

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Abstract— This paper presents two compact microstrip bandpass filters using inductive-coupled open stub-loaded resonator. The character of the open stub-loaded resonator is studied. One adjustable transmission zero above the pass band of the filters is got by the open stub, which greatly improves the stopband rejection of the filter. The short-circuited stub is introduced to generate inductive-coupling between the resonators. In order to create more transmission zeros, cross-coupling between the source and load is introduced in the second filter design. The simulated and measured results agree very well which has demonstrated the validation of our design.

1. INTRODUCTION

Recent advances in wireless communication have created a need for filters with low insertion loss, good stopband rejection and high selectivity for the modern microwave communication system design [1]. It is usually favorable that a filter has several transmission zeros which can suppress the useless frequency near the passband or improve the stopband rejection. Several methods have been proposed to produce transmission zeros, such as adopting proper cross-coupling between nonadjacent resonators [1–3], tapping microstrip line resonators [4], establishing separate multi coupling paths for adjacent resonators [5, 6].

A filter consists of a quarter-wavelength open stub between quarter-wavelength resonators was first reported in Ref. [7]. The filter has one transmission zero which can be adjusted by changing the length of the open stub. However, the proposed filter suffers from bad stopband suppression and only two transmission poles are got with three quarter-wavelength sections. Moreover, the first harmonic passband occurs at about $2f_0$. In the following years, this type of filter is developed by many researchers [8–10]. However, the problems still do not have completely solved.

In this paper, the open stub-loaded resonator can create both a transmission zero and a transmission pole. The short-circuit stub which equals to a K-inverter is used to generate inductive-coupling between adjacent resonators [11, 12]. The merit is the coupling can be controlled by the length of the short-circuit stub. In order to improve the performance of the filter, another third-order filter with source-load coupling is introduced to create more transmission zeros. In all, the implemented filters have a better stopband rejection and harmonic suppression compared with the filter in [7].

2. ANALYSIS OF THE OPEN STUB-LOADED RESONATOR

The proposed resonator structure composed of two short lines and a shunt open stub is shown in Fig. 1(a), where Z_1 and Z_2 are the characteristic impedances of the microstrip sections and θ_1 and θ_2 are the respective electrical lengths. l_1, l_2 are the corresponding physical lengths. The input

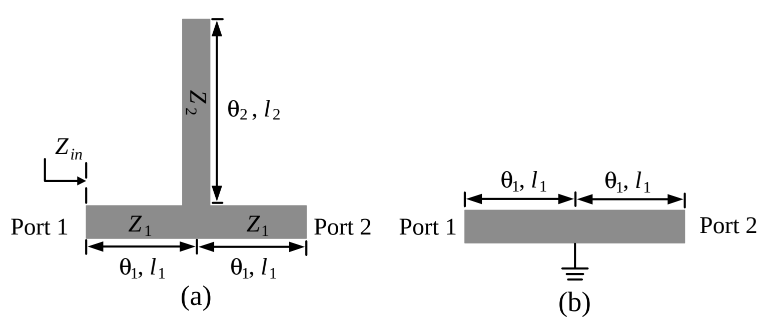

Figure 1: (a) Structure of the open stub-loaded resonator, (b) the equivalent circuit of the resonator when the open stub equals to a short circuit.

impedance of the resonator from port 1 is

$$Z_{in} = -jZ_1 \frac{Z_2 - \tan\theta_1(Z_2\tan\theta_1 + Z_1\tan\theta_2)}{2Z_2\tan\theta_1 + Z_1\tan\theta_2}. \quad (1)$$

The resonance condition can be obtained by letting $Z_{in} = 0$,

$$Z_2 - \tan\theta_1(Z_2\tan\theta_1 + Z_1\tan\theta_2) = 0. \quad (2)$$

It can be simplified as

$$\tan 2\theta_1 \tan\theta_2 = R_Z, \quad (3)$$

where R_z is the impedance ratio, $R_z = 2Z_2/Z_1$. By solving the above equation, we can get the fundamental resonant frequency f_1. On the other hand, an open circuit can equal to a short circuit by the open stub which plays a role as the $\lambda/4$ impedance inverter. If the center of the resonator is short-circuited as shown in Fig. 1(b), the energy from port 1 would be completely reflected and no energy would be transferred to port 2. Thus a transmission zero would be created. Let the open stub work as a $\lambda/4$ impedance inverter, we can get the frequency of the transmission zero which is expressed as

$$f_2 = \frac{c}{4\sqrt{\varepsilon_e} l_2}. \quad (4)$$

By changing l_2, we can adjust the location of the transmission zero. Fig. 2 shows the $2l_1 + l_2$ under different l_2 and R_z when $f_1 = 2\,\text{GHz}$. From the graph, for a certain l_2, the smaller R_z is, the shorter total length $2l_1 + l_2$ is. When $R_z = 1$, the total length stay the same for different l_2. Usually, l_2 is chosen a litter shorter than $\lambda/4$ at the filter's center frequency, to make the transmission zero near the passband. This would lead a good selectivity of the filter. On this condition, l_1 is very small as shown in Fig. 2. The total length $2l_1 + l_2$ would appropriate $\lambda/4$ at the filter's center frequency. Moreover, the open stub loaded resonator is very similar to a $\lambda/4$ SIR. When R_z is large, the first spurious response exhibits lower than $3f_1$, and vice versa. This phenomenon would be shown in the next section.

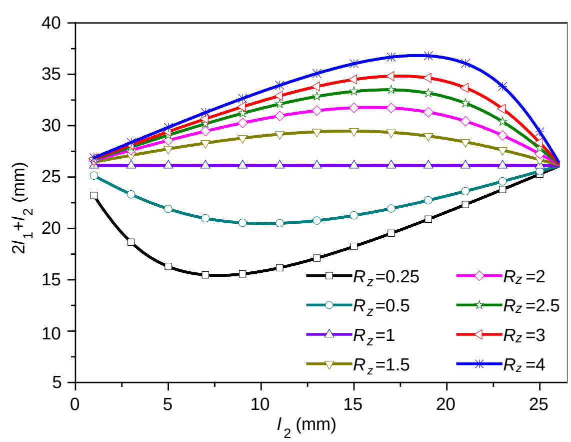

Figure 2: Solutions of $2l_1 + l_2$ for the given l_2 and R_Z.

3. THIRD-ORDER FILTER REALIZATION

In this section, a third-order filter has been designed as shown in Fig. 3(a). The open stub-loaded resonator is connected to two quarter-wavelength resonator by two short-circuit stub. The short-circuit stub can be equaled to a K-inverter. The coupling coefficient can be adjusted by the length of the short-circuit stub or the radius of the via. Here, Z_1 and Z_2 are both $41.3\,\Omega$. l_2 is 21.8 mm to have a transmission zero at 2.26 GHz.

The third-order filter is designed to have 280 MHz bandwidth at a center frequency of 2 GHz. The measured and simulated frequency response of the proposed filter is given in Fig. 3(b). A F4B substrate with relative dielectric constant of 2.45, loss tangent of 0.001, and thickness of 0.8 mm is chosen for the filter fabrication. The measured results exhibit an absolute bandwidth of 260 MHz at the center frequency of 1.95 GHz and the measured minimum insertion loss is 1.1 dB. A transmission zero is located at 2.22 GHz. The first spurious response is at about three times the center frequency. But the first spurious frequency of the open stub-loaded resonator is at 5.2 GHz which is lower than three times the center frequency 6 GHz. This is because its $R_z = 2 > 1$.

To validate the theory proposed in last section, other two filters using different open stub-loaded resonator are proposed. The filters have nearly the same bandpass response but different transmission zeros by choosing proper l_1 and l_2. Fig. 4 shows the simulated response of these filters. It can be seen that the transmission zero can be adjusted by choosing different l_2. The location of

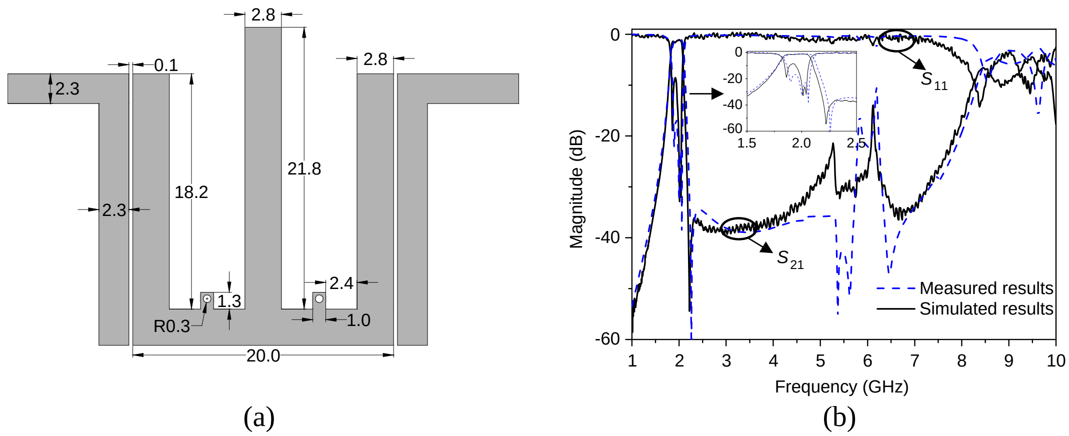

Figure 3: (a) Structure of the proposed third-order filter (unit: mm). (b) Simulated and measured results.

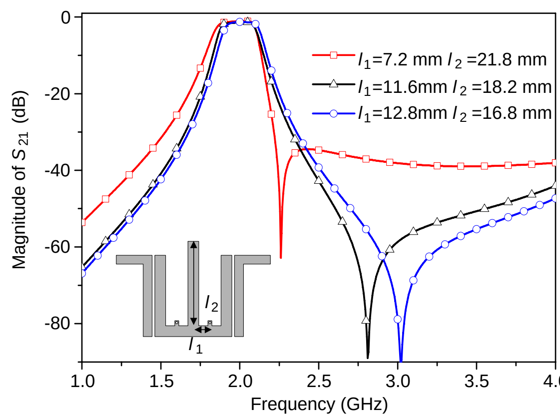

Figure 4: Filters' response with different l_1 and l_2.

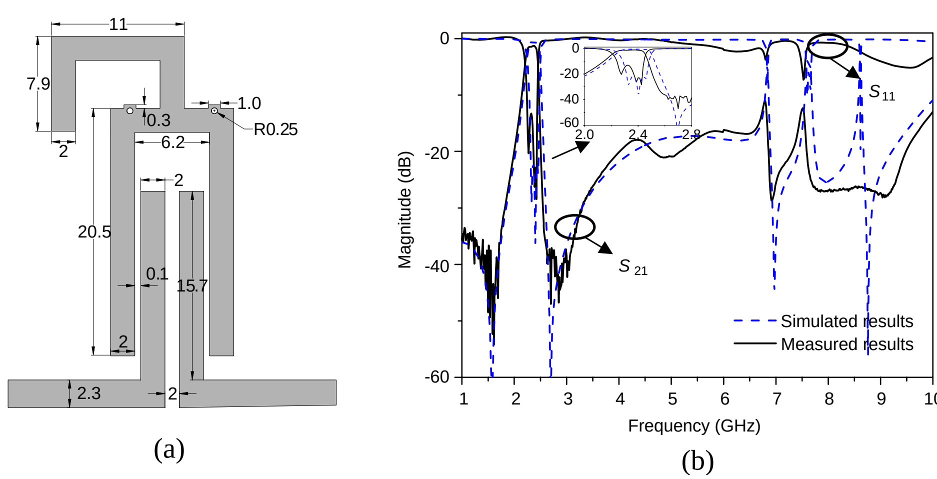

Figure 5: (a) Structure of the proposed third-order filter with source-load coupling (unit: mm). (b) Simulated and measured results.

the transmission zero is determined by Equation (4).

4. THIRD-ORDER FILTER WITH SOURCE-LOAD COUPLING

To produce more transmission zeros, another third-order cross-coupled filter is implemented as illustrated in Fig. 5(a). The input and output feedlines are capacitive-coupled to each other compared with the proposed filter structure in Section 3. The filter is designed to have a center frequency of 2.4 GHz and a fractional bandwidth of 10%. The measured and simulated results of the proposed filter are shown in Fig. 5(b). The implemented filter has a center frequency of 2.33 GHz, minimum insertion loss of 1.28 dB at 2.375 GHz, and 3-dB bandwidth of 10.2%. Two transmission zeros are located at about 1.6 GHz and 2.6 GHz respectively.

5. CONCLUSION

In this study, two novel microstrip bandpass filter using inductive-coupled open stub-loaded resonator has been proposed and carefully examined. By employing open stub-loaded resonator, the proposed filters exhibit one adjustable transmission zero at upper stopband which can be tuned by the length of the open stub. In addition, to produce more transmission zeros, the source-load coupling is added to the filter design. The proposed filters are useful for applications in the communication systems when low insertion loss and good stopband rejection are required.

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