Compact Microstrip Coupled-Line Bandpass Filter With Two Cross-Couplings for Creating Multiple Transmission Zeros

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Abstract — **A compact coupled-line bandpass filter with two capacitively cross-coupled paths to create multiple transmission zeros is proposed. The locations of transmission zeros can be adjusted by varying the values of cross-coupled capacitances so as to improve the filter selectivity. Specifically, a 4th-order microstrip coupled-line bandpass filter centered at 4.9 GHz with a 3-dB bandwidth of 6% and six transmission zeros is implemented and examined.**

I. INTRODUCTION

In microwave communication system design, a filter with compact size, low insertion loss, and good selectivity is usually needed to reduce the cost and to enhance the system performance. In order to achieve better selectivity, many improvements on creating suitable transmission zeros were reported. In [1]-[2], the filters with a cross-coupling between resonators to generate transmission zeros were examined. Multiple transmission zeros were obtained by using suitable input, output, and interstage tapped-couplings [3]. In [4]-[5], quarter-wavelength (λ/4) open stubs and capactively coupled gaps were introduced in the conventional coupled-line filter structure to create the transmission zeros at stopband. The trisection and quadruplet microstrip bandpass filters [6]-[7] based on folded λ/4 resonators were proposed to achieve very compact circuit sizes with one or two transmission zeros. The compact hairpin filter with asymmetric tapping feed lines to produce transmission zeros was also discussed in [8]-[9]. In our previous works [10]-[12], by introducing a capacitive cross-coupling effect, two transmission zeros at upper and lower stopbands may be created for improving the filter selectivity.

In this study, the 4th-order microstrip bandpass filter discussed in [13] and shown in Fig. 1 is extended to develop a novel filter structure as shown in Fig. 2 which has two capacitive cross-couplings to create multiple transmission zeros. Comparing with the basic 4th-order bandpass filter in Fig. 1 which has a cross-coupled path provided by the capacitance C_2, the proposed filter has an additional cross-coupled capacitance C_3 introduced directly between the input and output ports as shown in Fig. 2. Therefore, the new filter structure may create multiple transmission zeros at the upper and lower stopbands such that the selectivity of the proposed filter may further be improved while keeping the same circuit size.

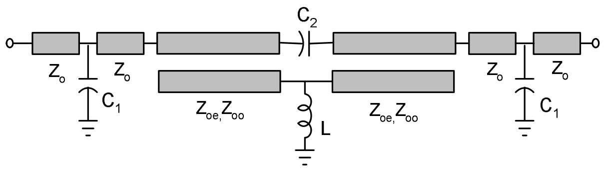


Fig. 1. Circuit model of the 4th-order bandpass filter in [13] with a capacitively cross-coupled path to create two transmission zeros.

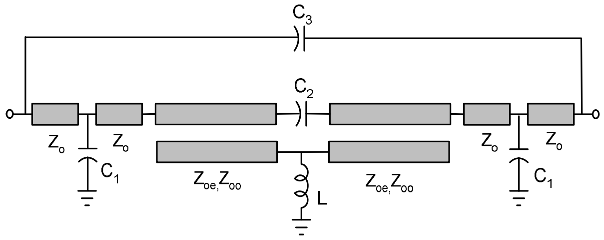


Fig. 2. Circuit model of the proposed 4th-order bandpass filter with two capacitively cross-coupled paths to create multiple transmission zeros.

II. FILTER STRUCTURE AND IMPLEMENTATION

Fig. 2 shows the proposed filter circuit model with two capacitively cross-coupled paths to create multiple transmission zeros. By neglecting the cross-coupling effects, i.e. $C_2 = C_3 = 0$, the coupled-line section with open circuited terminal may be equivalent to a J inverter along with two transmission lines for narrow band [14] and the shunt capacitor C_1 or inductor L with two transmission line sections at its two ends may be equivalent to a K inverter [15]. Thus, the equivalent circuit model is the same as the one in [13].

Based on the circuit model in Fig. 2, a novel 4th-order microstrip coupled-line bandpass filter is implemented as in Fig. 3 which has two cross-coupled capacitors C_2 and C_3 to generate four to six transmission zeros depending on the values of capacitances C_2 and C_3. Here, the cross-coupled capacitor C_2 is realized by the gap-coupled configuration between the open-ends of two coupled-line sections. In order to achieve the desired amount of cross-coupling through the capacitor C_3, the two coupled-lines are bended by an angle θ_1 and the transmission-line sections by an angle θ_2. The shunt capacitors C_1 are

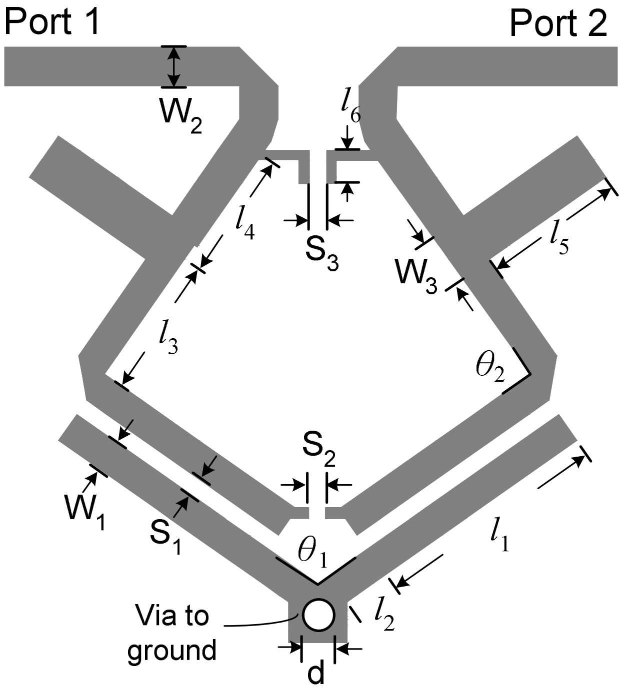


Fig. 3. Layout of the proposed 4th-order microstrip coupled-line bandpass filter with two capacitive cross-couplings to create multiple transmission zeros. (W_1=0.97mm, S_1=0.5mm, W_2=1.17mm, S_2=0.3mm, W_3=1.53mm, S_3=0.15mm, l_1=7.08mm, l_2=1.4mm, l_3=4.3mm, l_4=4.2mm, l_5=4.3mm, l_6=0.8mm, θ_1=70°, θ_2=90°, and d=1.1mm.)

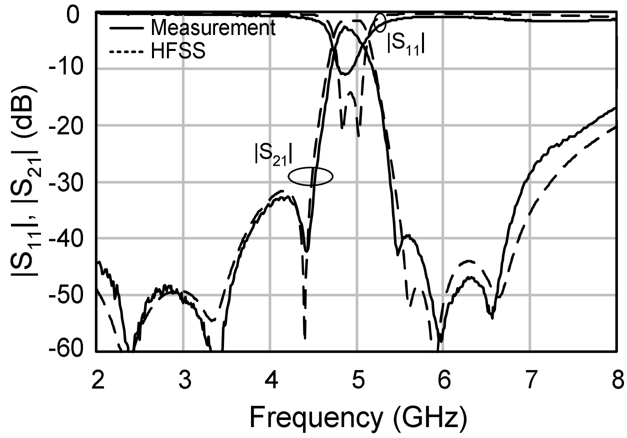


Fig. 4. Measured and simulated results for the proposed 4th-order microstrip coupled-line bandpass filter shown in Fig. 3.

accomplished by the open stubs and the inductor L is realized by the via hole so as to fit the values of the K inverters.

The proposed filter structure is implemented using the microstrip configuration, and is fabricated on a Rogers RO4003c substrate (ε_r = 3.38, tanδ = 0.0023, and thickness h= 0.508 mm).The simulated results by the full-wave simulator HFSS and the measured ones for the filter in Fig. 3 are shown in Fig. 4. The measured center frequency is at 4.9 GHz. The minimum measured insertion loss is 2.5 dB at 4.87 GHz, and the 3-dB bandwidth is 6%. Six transmission zeros at 2.38 GHz, 3.34 GHz, 4.33 GHz, 5.39 GHz, 5.89 GHz, and 6.48 GHz

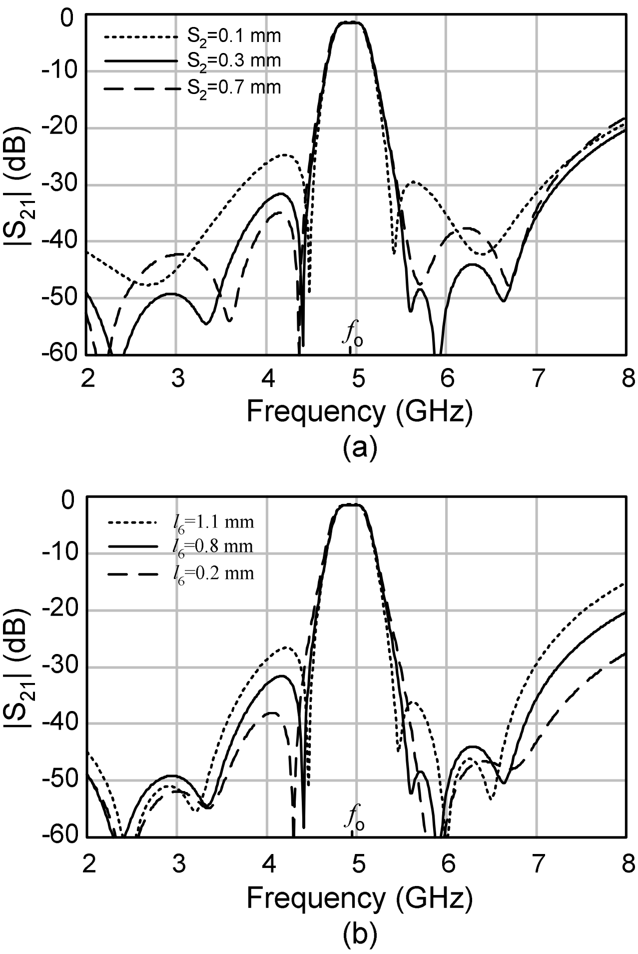
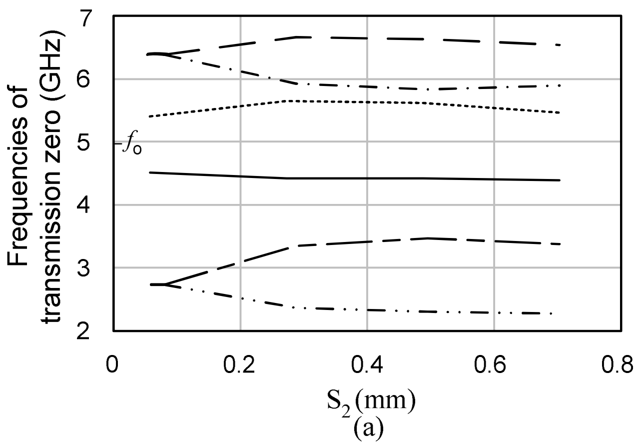


Fig. 5. Full-wave simulated responses of the proposed 4th-order microstrip filter in Fig. 3 for (a) various values of S_2 to control the values of capacitance C_2, (b) various values of l_6 to control the values of capacitance C_3.

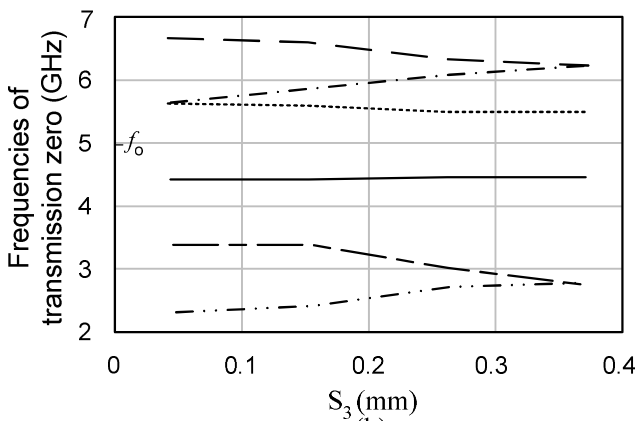
are observed as expected. Note that the inclusion of the cross-coupled capacitor C_3 has created the multiple transmission zeros to improve the filter selectivity but at the expense of degrading the stopband rejection level.

III. Transmission Zeros

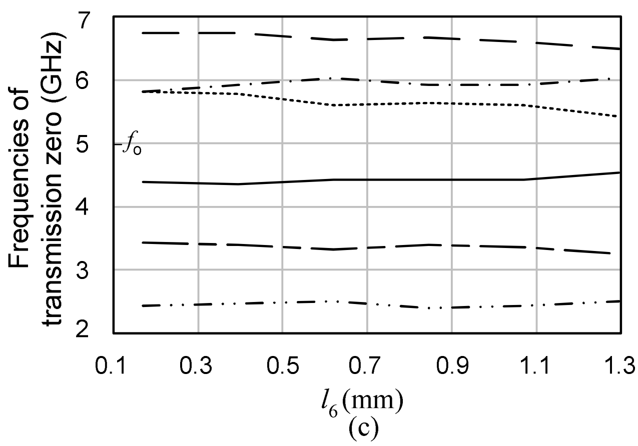
The locations of transmission zeros for the proposed filter may actually be adjusted by varying the parameter S_2 (Fig. 3) to control the value of C_2 and the parameters l_6 and S_3 to control that of C_3. Shown in Fig. 5 are the full-wave simulated responses of the proposed filter with S_2 and l_6 in Fig. 3 as parameters. As shown in Fig. 5(a), the two left-most transmission zeros (with respect to the passband center frequency f_o) will move and close to each other and the transmission zeros at upper stopband will move toward the passband edge as the parameter S_2 is decreased to increase the value of C_2. For the case S_2 = 0.1 mm, only four transmission zeros are observed because some of transmission zeros would be too close to be distinguishable. As shown in Fig. 5(b), the inner pair of transmission zeros will move toward the passband edge and the stopband rejection level will degrade as the



(a)



(b)



(c)

Fig. 6. Full-wave simulated curves to relate the frequencies of transmission zeros to the parameters (a) S_2 (l_6 = 0.8mm, S_3 = 0.15mm), (b) S_3 (l_6 = 0.8mm, S_2=0.3mm), and (c) l_6 (S_2 = 0.3mm, S_3=0.15mm) in Fig. 3.

parameter l_6 is increased to increase the value of C_3. For the case l_6 = 0.2mm, the frequency response only has five transmission zeros. Therefore, according to the movement tendency of transmission zeros in Fig. 5, the values of C_2 and C_3 can be determined for the desired locations of the transmission zeros so as to achieve the required fall-off rate at the passband edge and the desired level of stopband rejection.

Shown in Fig. 6 are the detail full-wave simulated curves to relate the frequencies of the transmission zeros to the parameters S_2, S_3, and l_6. Comparing Fig. 6(b) with Fig. 6(c), the parameter S_3 has more influence than l_6 on the frequencies of transmission zeros. The parameter S_3 can first be selected and the parameter l_6 is then tuned to fit the specification. Some transmission zeros would be too close to be distinguishable as the parameter S_3 is increased or decreased. Note that the frequencies of transmission zeros might slightly be changed because of the dimensions variation in the fabrication process.

IV. Conclusion

In this work, a compact 4th-order microstrip bandpass filter with multiple transmission zeros has been proposed. By introducing two capacitively cross-coupled paths, the proposed filter exhibits multiple transmission zeros at upper and lower stopbands. The locations of these transmission zeros may simply be adjusted by varying the values of cross-coupled capacitances. The proposed bandpass filter is useful for application in the communication systems when better selectivity and good stopband rejection are required.

Acknowledgement

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