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MICROSTRIP BANDPASS FILTERS USING TRIPLE-MODE PATCH-LOADED CROSS RESONATOR

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Abstract—Microstrip bandpass filters using a triple-mode patch-loaded cross resonator are presented in this work. First, a square patch is added at the center of a cross resonator to separate the resonant frequencies of the 1st and 2nd modes. Then, a pair of narrow slots is etched into the square patch along its symmetrical plane to split the 1st resonant mode and its degenerate mode. By changing the patch size and the slot length, the above three modes are appropriately adjusted. Two prototype filters with open-ended and stub-loaded coupled-lines are designed and fabricated to verify the design principle and to further suppress the lowest harmonic passband, respectively. Predicted results agree well with the measured ones.

1. INTRODUCTION

Triple-mode resonator based bandpass filters have been an intensive research subject since they are much more promising than their dual-mode counterparts in size compactness and sharp out-of-band roll-off skirt. As a pioneering work in this aspect, a triple-mode cavity resonator has been proposed and investigated in [1]. However, the cavity-based filter is bulky and difficult to be integrated with other planar microwave circuits. Recently, much research attention has focused on the exploration of planar triple-mode bandpass filters with relatively narrow fractional bandwidth [2–6]. In [2], a half-wavelength transmission-line with two dissimilar stubs attached at the center is developed to create a three-pole passband filter with two transmission zeros. In [3, 4], two modified stub-loaded resonators are proposed to improve the filtering performance via reshaping the upper and lower

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stubs. However, to introduce transmission zeros on the two sides of the passband and to enlarge the bandwidth of the filter, the upper and lower stubs are in dissimilar shapes. In [5], a square loop resonator is placed inside a metallic cavity to properly lower its TM_{210} mode within the desired passband of a dual-mode filter. Very recently, a planar triple-mode bandpass filter by cutting a set of slots into the edge of a circular patch has been proposed in [6], which utilizes the two lowest degenerate modes and the second lowest mode. In [7], a hexagonal loop resonator has been proposed. By adding one open capacitive and three radial-line stubs, the third order mode is declined

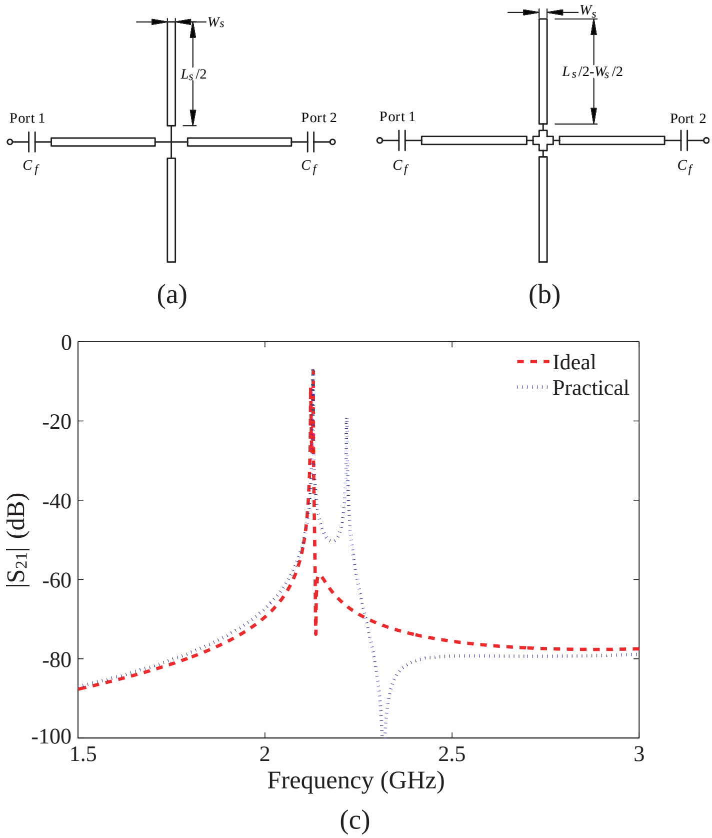


Figure 1. The schematic of the cross resonator. (a) Ideal case. (b) Practical case with the cross junction in the center, and for the two cross resonators, they are with the same electric length and under weak coupling condition ($C_f = 0.001\,\text{pf}$, $W_s = 0.4\,\text{mm}$ and $L_s = 27.2\,\text{mm}$). (c) Frequency responses for the two cross resonators.

next to the first order degenerate modes.

In this work, a patch-loaded cross resonator on microstrip is proposed for two triple-mode bandpass filter designs. By loading a square patch in the center of a cross resonator, the 1st and 2nd resonant modes are separated. To split the 1st degenerate mode pairs, a pair of slots are symmetrically etched into the patch. Open-ended and stub-loaded coupled lines are respectively used to verify the design principle. The designs are on a substrate with relative dielectric constant of 10.8, thickness of 50 mils, and copper thickness of 0.017 mm.

2. TRIPLE-MODE CROSS RESONATOR

First, the cross junction effect of the cross resonator is discussed. Fig. 1(a) and Fig. 1(b) illustrates two cross resonator, one is the ideal case, and the other is the practical one with a cross junction in the center. The two cross resonators are with the same electrical length. Fig. 1(c) shows the frequency responses for the two cross resonators. For the ideal case, only one resonant pole is observed, indicating that the first two modes resonate at the same frequency. For the practical case, there are two resonant poles, indicating one of the first two modes is driven to a higher resonant frequency. As discussed in [8], this is caused by the cross junction effect involved with this type of resonator.

In Fig. 2, a cross resonator is loaded with a square patch at the center, with the purpose to enlarge this cross junction effect. The

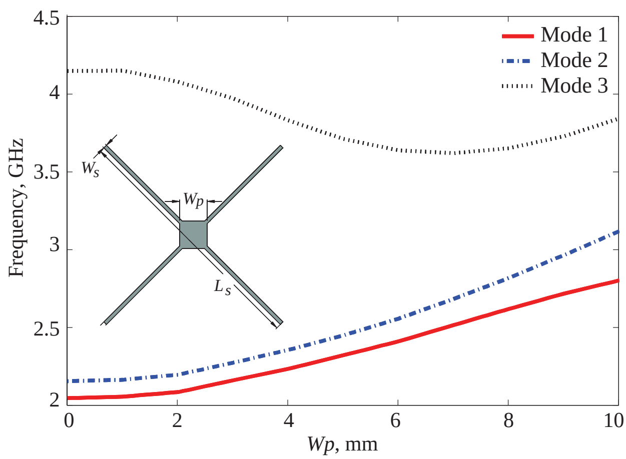


Figure 2. Resonant frequencies of the first three modes versus patch size (W_p) (W_s=0.4 mm and L_s=27.2 mm), with the illustration of the schematic of the patch loaded cross resonator.

variations of the first three resonant frequencies of this resonator are plotted in Fig. 2. As the patch size (W_p) increases, the cross junction in the center of the patch is enlarged. Therefore, the spacing between the resonant frequencies of Mode 1 and Mode 2 undergo an gradually increase. Because the loaded patch lowers the impedance of the microstrip in the center, the resonant frequencies of Mode 1 and Mode 2 increase slightly as the patch size increases. Mode 3 forms the first harmonic passband for the proposed filters, which will be discussed later.

Then, a pair of identical narrow slots is etched into the patch along its symmetrical plane, as shown in Fig. 3. Three sets of transmission coefficients for different L_c values under weakly capacitive coupling are plotted. Since the slot is on the electric and magnetic wall of Mode 1 and its degenerate mode. As L_c increases, the resonant frequencies of Mode 1 are nearly unchanged, but its degenerate mode monotonically goes down. As such, the spacing between the resonant frequencies of Mode 1 and its degenerate mode can be appropriately enlarged [9]. Since the surface current of the Mode 2 bends in the patch, the slot hardly influences its distribution. Thus, its resonant frequency is almost un-affected. When L_c=1.4 mm and W_c=0.4 mm, the three modes of interest are quasi-equally spaced with each other, which provides a physical basis in exploration the triple-mode cross-resonator filters.

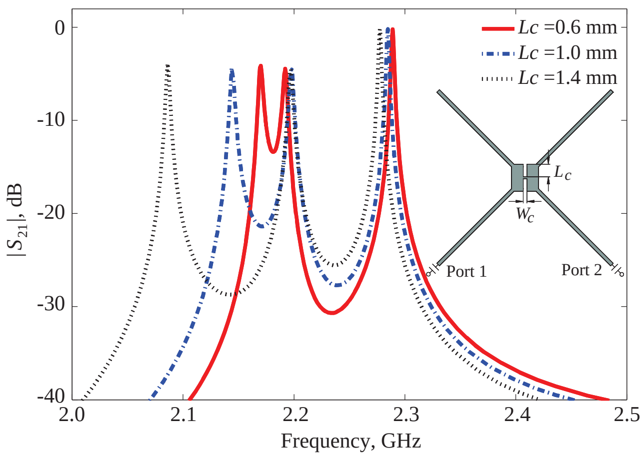
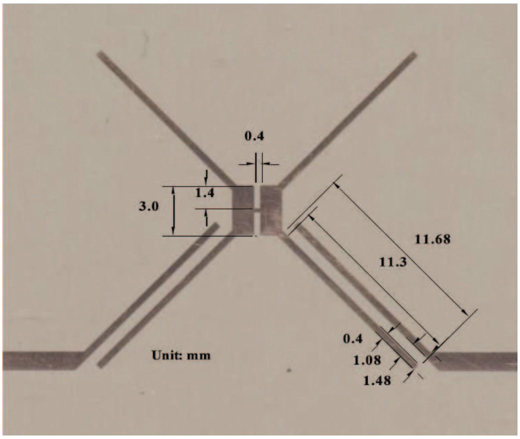


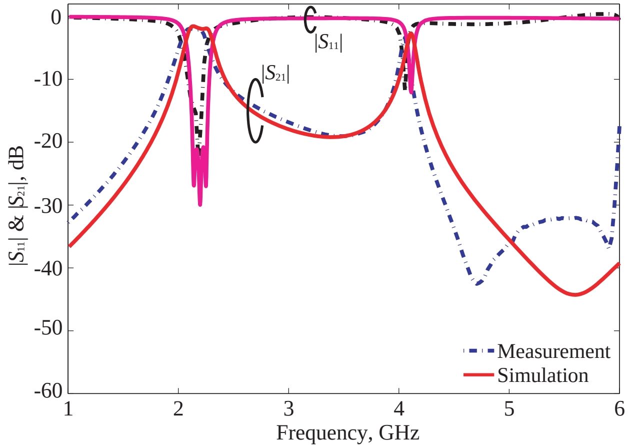
Figure 3. $|S_{21}|$ response under different slot length (L_c) (W_s=W_c=0.4 mm, L_s=27.2 mm and W_p=3 mm), with the illustration of the slotted-patch loaded resonator capacitively coupled by 90°-oriented feed lines.

3. FILTERS DESIGN AND EXPERIMENTAL RESULTS

Open-ended coupled lines of 90°-orientation are used for the initial triple-mode bandpass filter design, that is, Filter I, as shown in Fig. 4(a). By adjusting the length and spacing of the coupled line, the triple-mode passband can be realized. Fig. 4(b) plots the measured and simulated results, showing a passband at 2.15 GHz, 3-dB fractional bandwidth of 11.1%, and minimum insertion loss of about 2.15 dB.



(a)



(b)

Figure 4. (a) Photograph of the fabricated Filter I. (b) Simulated and measured frequency responses of Filter I.

However, Filter I seriously suffers from a harmonic passband at around 4.2 GHz due to the unexpected resonance of Mode 3.

To suppress this harmonic passband, stub-loaded coupled lines are used for a modified triple-mode filter design, namely, Filter II. Compared with the open-ended coupled lines, the stub-loaded coupled lines provide an almost identical coupling degree and create a

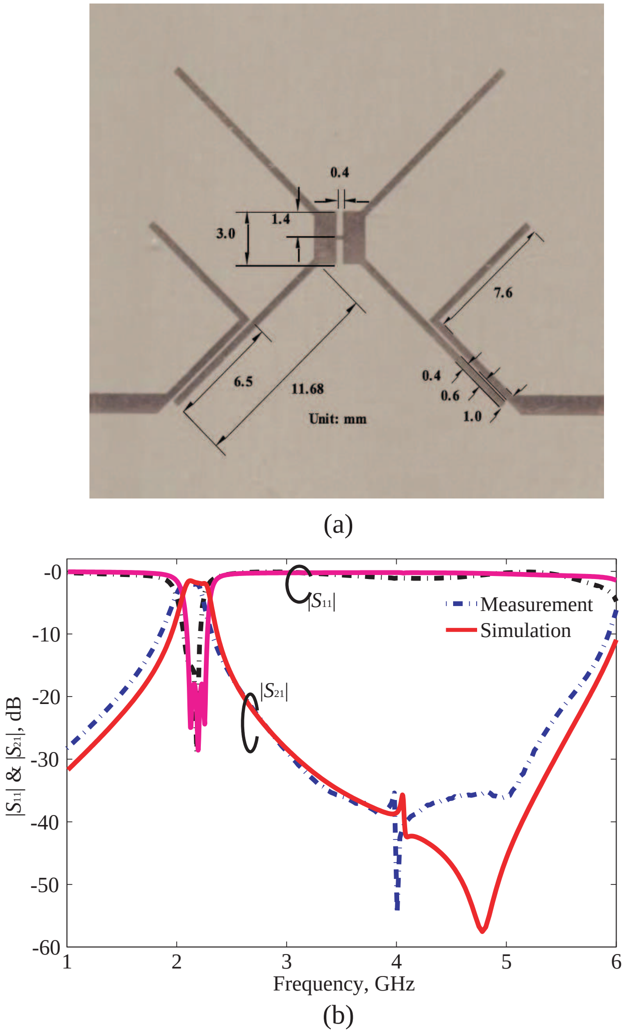


Figure 5. (a) Photograph of the fabricated Filter II. (b) Simulated and measured frequency responses of Filter II.

transmission zero near 4.2 GHz. Fig. 5(a) shows the photograph of the fabricated filter with all the dimensions marked. As shown in Fig. 5(b), the measured and simulated in-band frequency responses are nearly unchanged compared with those of Filter I. But Filter II achieves more than 35.0 dB rejection at around 4.2 GHz.

Based on the two examples described above, the filter design process is summarized below. Given the center frequency and the fractional bandwidth, a square patch is used to enlarge the spacing of first two modes. Then, a pair of slots is etched into the patch to split the first degenerate mode pairs. Next, after the three modes are quasi-equally distributed within the desired passband, stub-loaded coupled lines are used to feed the proposed resonator and to suppress the first harmonic passband.

4. CONCLUSION

Two triple-mode microstrip bandpass filters using slotted-patch loaded cross resonator are proposed. The 1st and its degenerate mode as well as its 2nd mode are simultaneously excited by placing a slotted-patch in the center of a cross resonator for design of a novel three-mode bandpass filter. Final, two prototype filters are designed and fabricated to verify the design principle.

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