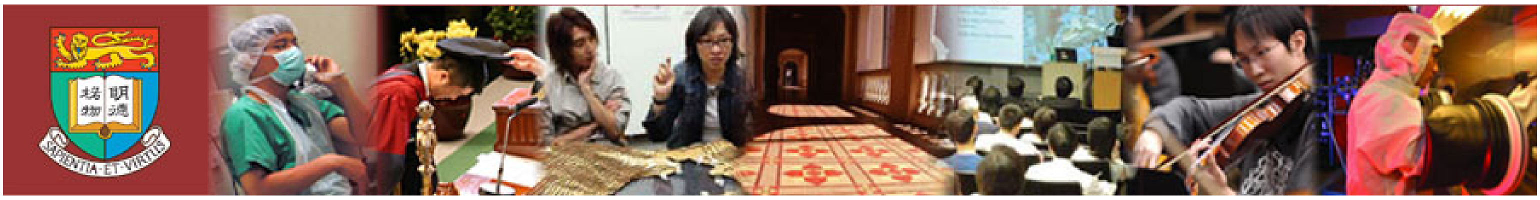

New Studies on Microstrip Ring Resonators for Compact Dual-Mode Dual- and Triple-Band Bandpass Filters

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***Abstract*— This paper deals with the proposal, design and implementation of a class of compact dual- and triple-band bandpass filters with two transmission poles in each passband using a single microstrip ring resonator. Two methods are first presented to design two types of dual-mode dual-band bandpass filters using a single resonator. One is to synchronously excite the two pairs of the first and third-order degenerate resonant modes of a ring resonator; the other is to use the first two pairs of degenerate resonant modes of a ring resonator. To achieve these targets, the port-separation angle along a ring is chosen as 45º/135 º, respectively. Inspired by these two methods, the first three pairs of degenerate modes of a ring resonator are further explored to design a compact dual-mode triple-band bandpass filter on a single resonator. The operating principle and design procedure for all filters are described clearly based on their equivalent transmission-line model. Several prototype filters are finally designed, fabricated and measured. The measured results show the two visible poles in each passband, thus evidently proving our proposed design theory.**

I. INTRODUCTION

Microstrip ring resonators have been widely used in various microwave circuits such as antennas, filters, couplers, oscillators, and mixers [1]. It is well known that there are two degenerate modes coexisting in each resonance of a ring resonator, which results in compact size and high quality (Q) factor. The internal coupling between the two resonant modes can be created to split them by either changing the port-separation angle or applying perturbation in a plane that is orthogonal to the ring resonator [2].

The primary objective of this paper is to use a single microstrip ring resonator for exploration of a novel class of compact dual-mode dual- and triple-band bandpass filters. Typically, two resonators are required to generate two transmission poles in each passband for design of a multi-band bandpass filter. By using only one ring resonator, the overall size of a dual- or triple-band bandpass filter can be significantly reduced. In this paper, both the first- and third-order degenerate modes, and the first two pairs of degenerate modes are applied to design dual-mode dual-band bandpass filters using a single ring resonator as has been extensively

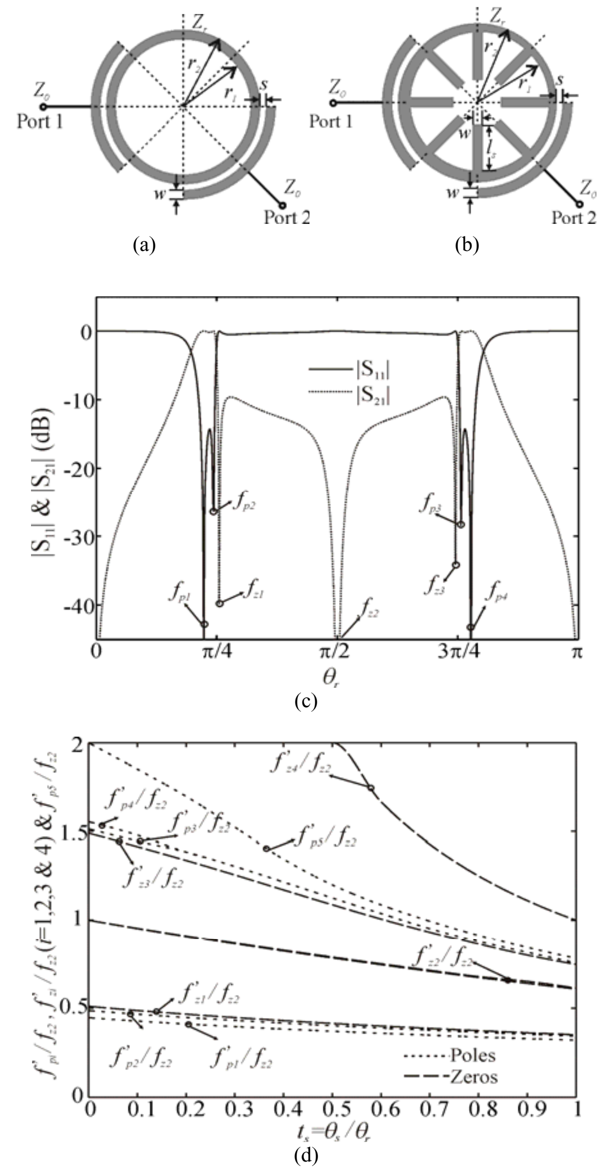


Fig. 1. Proposed dual-mode dual-band bandpass filter. (a), (b) single uniform and stub-loaded ring resonator filters. (c) Simulated S-parameters of the filter in (a). (d) Transmission poles and zeros versus normalized stub length

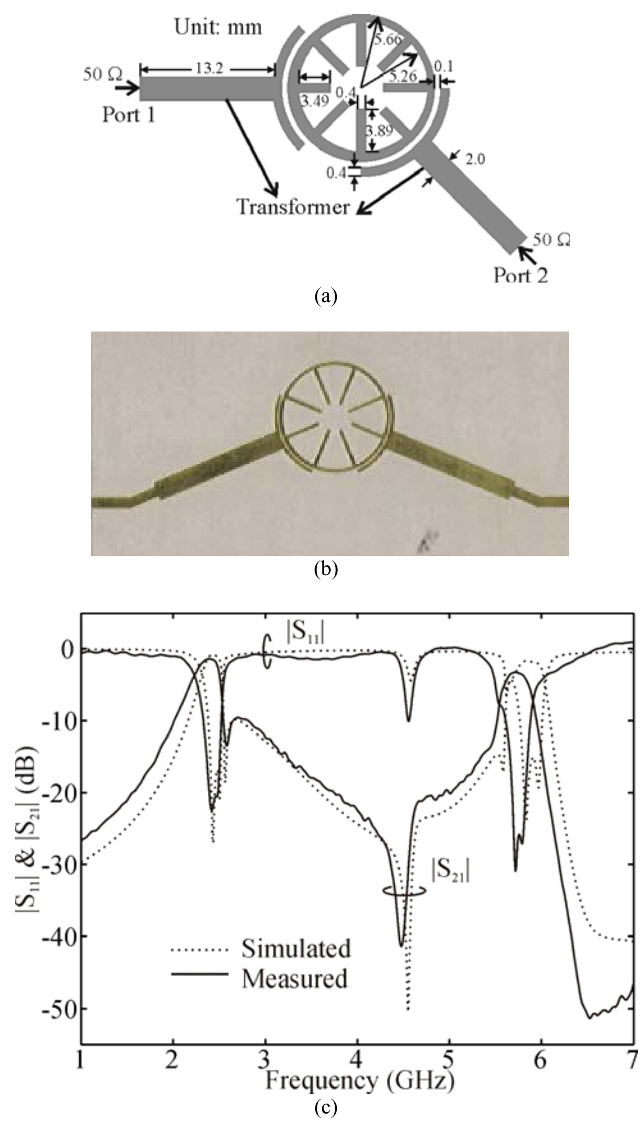


Fig. 2. Modified dual-mode dual-band bandpass filter for fabrication and measurement. (a) Layout. (b) Photograph. (c) Simulated and measured frequency responses.

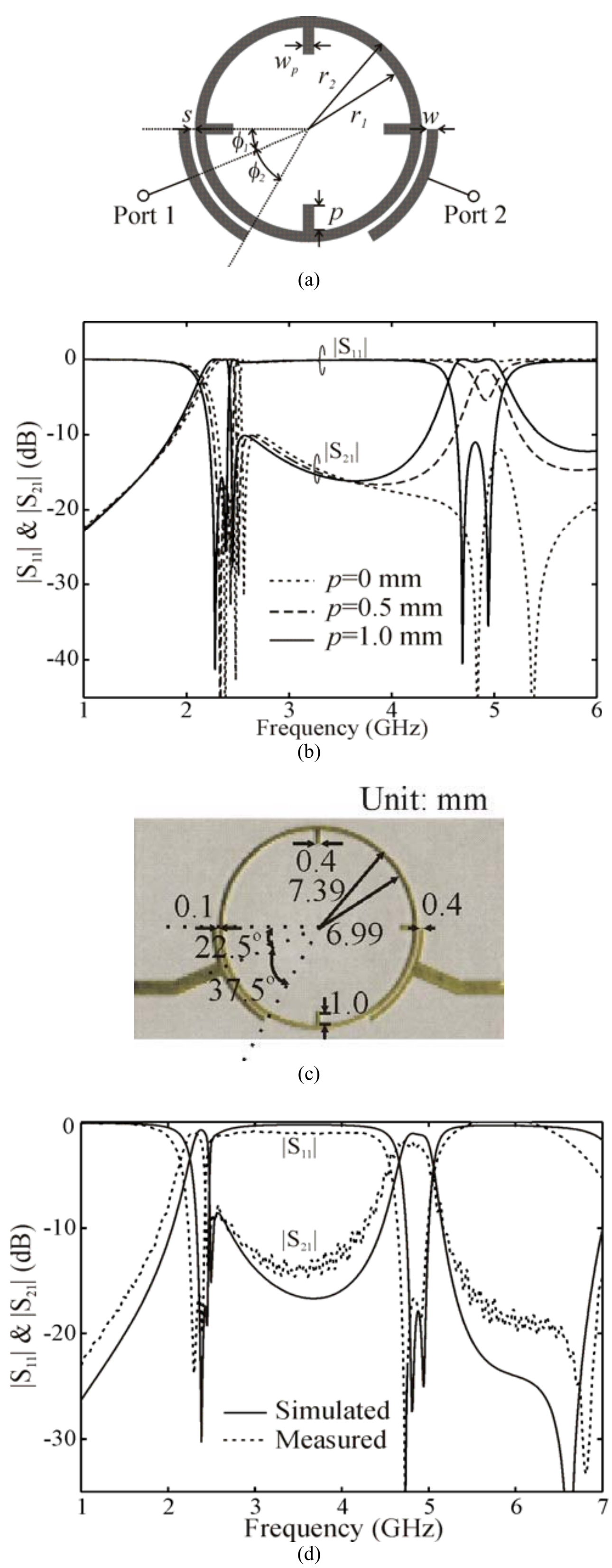


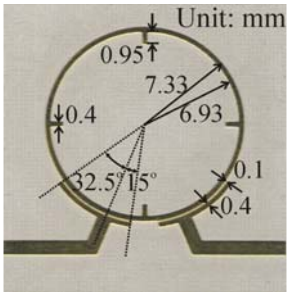
Fig. 3. (a) Schematic of the proposed ring resonator. (b) Frequency responses of S-magnitudes under varied stub lengths (p). (c) Photograph and (d) Simulated and measured frequency responses of a fabricated filter circuit.

reported in [3]-[5]. Moreover, the proposed concept is extended to design a novel planar dual-mode triple-band bandpass filter on a single ring resonator [6]. After describing their operating mechanism and design principle, several dual-mode dual- and triple-band bandpass filters are designed, fabricated and measured. All the filters are implemented on a dielectric substrate with a thickness of 1.27 mm and permittivity of 10.8. The good agreement between the simulated results from ADS full simulator [7] and measured results verifies the proposed design theory.

II. DUAL-MODE DUAL-BAND BANDPASS FILTERS

A. The first- and third-order degenerate modes

Fig. 1(a) and (b) depicts the schematic of the proposed dual-mode dual-band microstrip ring resonators, where Z_0 is the input and output port impedances, r_1 and r_2 are the inner and outer radii of this ring, and Z_r is the characteristic impedance



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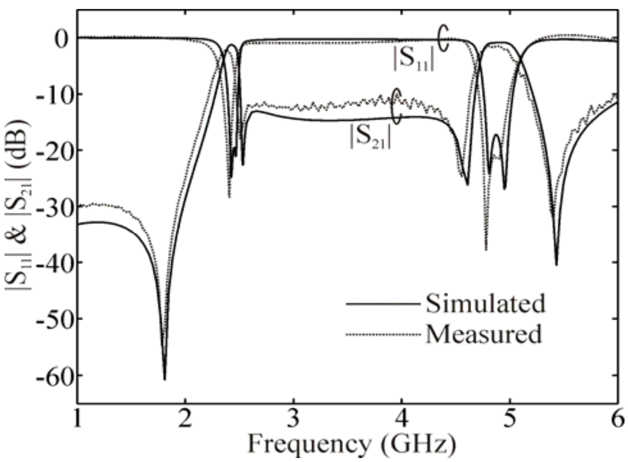
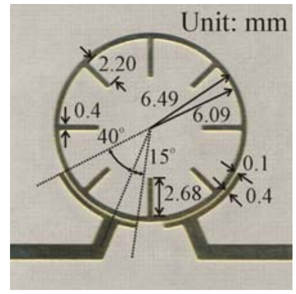
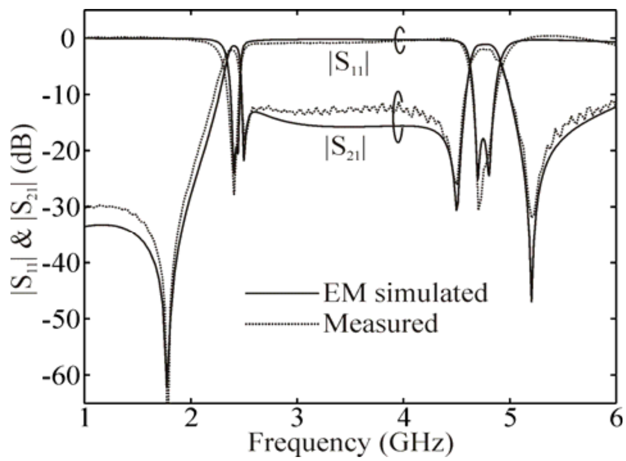


(b)

Fig. 4. (a) Photograph of the fabricated filter with four attached stubs. (b) Simulated and measured results.



(a)



(b)

Fig. 5. (a) Photograph of the fabricated filter with eight attached stubs. (b) Simulated and measured results

of the ring. In our design, the parallel-coupled lines are one quarter of the overall length of the ring, with a width of w or r_2- r_1 and a spacing of s. The two excited ports are placed along the ring with a separation angle of 135° and they are capacitively coupled to this ring via parallel-coupled lines.

As shown in Fig. 1(c), the first- and third-order degenerate modes appear at different frequencies, which can be properly adjusted by the coupling strength of the parallel-coupled lines. Meanwhile, the second-order degenerate modes resonate at the same frequency and they can be fully suppressed by a transmission zero. After adjusting a pair of transmission poles in each passband, eight open-circuited stubs are attached to the ring resonator in order to adjust the ratio of the center frequencies as well as to minimize the overall filter size. The transmission poles and zeros tends to be moved up and down with the increment of the stubs as plotted in Fig. 1(d). Based on the curves in Fig. 1(d), a stub-loaded dual-mode dual-band bandpass filter with operating frequencies of 2.4 and 5.8 GHz is designed and implemented. The layout and the photo of the fabricated ring bandpass filter are shown in Fig. 2(a) and (b). The simulated and measured results are plotted together in Fig. 2(c). Visibly, the two expected transmission poles actually exist in both the first and the second passbands at the two desired center frequencies.

B. The first- and second-order degenerate modes

Fig. 3(a) illustrates the schematic of the proposed second type of dual-band dual-mode microstrip ring resonator that is fed via parallel-coupled lines with a port-separation angle of 135°. The four identical open-circuited stubs have widths of w_p and lengths of p. Without any perturbation introduced in the ring (i.e., p=0 mm), there only exists a dual-mode passband at f_0, as shown in Fig. 3(b). This figure also shows that as p increases from 0.5 to 1.0 mm, the second-order degenerate modes are split to realize the second passband with one to two poles. Fig. 3(c) shows the photograph of the fabricated filter circuit. In Fig. 3(d), the measured results are plotted together with the simulated results. It is experimentally confirmed that there exist two transmission poles in both of the first and second passbands at the frequencies of 2.3 and 4.8 GHz, respectively.

As demonstrated in [5], the same phenomenon can be repeated using a ring resonator with a port-separation angle of 45°. Fig. 4(a) shows the photograph of the fabricated filter circuit, and the simulated and measured results are plotted in Fig. 4(b). It shows good agreement between them over a wide frequency range of 1.0 to 6.0 GHz. Moreover, four transmission zeros (1.79, 2.51, 4.54 and 5.39 GHz) are observed at both sides of each passband, thereby improving filtering selectivity. To further miniaturize the overall circuit size, an alternative ring resonator is formed by adding four additional open-circuited stubs. As shown in Fig. 5(a), eight stubs have been employed here and allocated symmetrically along the ring in order to allow for sufficient spacing between them. With the help of eight perturbation stubs, the overall physical area of the ring resonator is reduced by 22% due to the increased slow-wave factor. The EM simulation and measurement results are plotted in Fig. 5(b), showing the expected dual-mode, dual-band filtering performance.

III. Dual-Mode Triple-Band Bandpass Filter Design

Based on both the above-described methods, the first three pairs of degenerate modes can also be used to design a dual-mode triple-band bandpass filter using a single ring resonator. The first- and third dual-mode passbands can be excited under a fixed 135°/45° port-separation angle of a ring; four open-circuited stubs are then attached to the uniform ring at an equally-spaced distance to split the second-order degenerate modes, thus making up the second passband with two poles. Two photographs of the fabricated filters with port-separation angles of 135° and 45° are provided in Fig. 6(a) and (b), respectively. Fig. 6(c) and (d) indicate their simulated and measured results, showing three passbands with two poles in each passband.

IV. Conclusion

In this paper, a novel class of dual-mode dual- and triple-band bandpass filters has been presented and implemented on a single microstrip ring resonator. Single ring dual-mode dual-band bandpass filters have been designed by synchronous excitation of its first- and third-order and its first pairs of the degenerate modes, respectively. Both methods have been combined to design dual-mode triple-band bandpass filters using the first three pairs of a single ring resonator. The operation principles and design procedure have been described. Several dual-mode dual-and triple-band bandpass filters have been successfully developed. The measured results have experimentally verified our proposed filter topologies.

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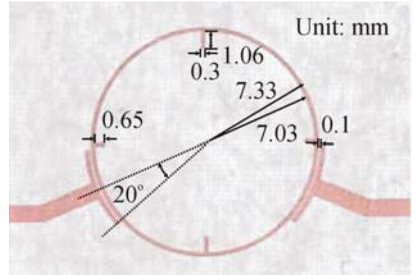

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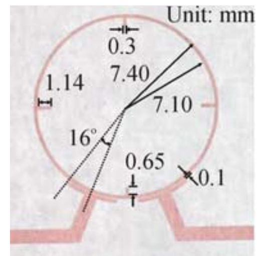

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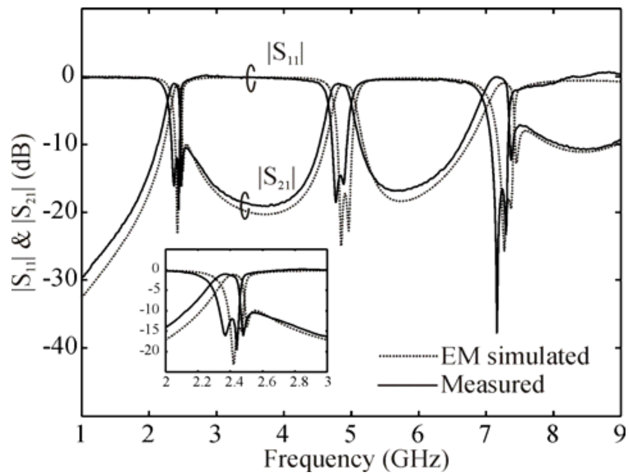

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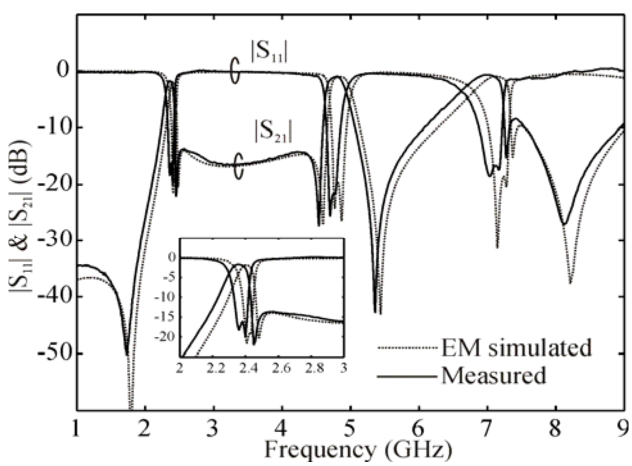

(d)

Fig. 6. Photograph of the fabricated filters with port-separation angles of (a) 135°and (b) 45°. Simulated and measured S_{21} and S_{11} magnitudes of the fabricated filters with port-separation angle of (c) 135°and (d) 45°.