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Microstrip dual-mode filters with miniaturized size and broadened stopband using meander-shaped stepped-impedance ring resonator

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Abstract: An improved class of microstrip dual-mode bandpass filter is proposed using the meander-shaped stepped-impedance ring resonator (SIRR). This meander SIRR, together with a uniform impedance ring resonator (UIRR), is at first studied to demonstrate its attractive features of harmonic-resonance suppression and overall-size miniaturization. A pair of squared notches is then etched out on the corners along either of diagonal lines of this symmetrical SIRR that is capacitively driven by the two perpendicular feed lines. Two SIRR-based dual-mode filters are therefore designed, simulated and fabricated. The overall size of this filter finds to be reduced by about 50% in area. The 1st harmonic passband of this filter is raised to 5.30 GHz that exceeds the three times of its fundamental passband at 1.52 GHz as verified by experiment.

Keywords: dual-mode bandpass filter, stepped impedance ring resonator, size miniaturization and harmonic suppression

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Various microstrip dual-mode bandpass filters have been extensively studied and implemented in the past several years [1, 2, 3, 4, 5, 6, 7, 8]. The concept of a microstrip ring dual-mode filter was originally proposed in [1] by setting up the two perpendicular feed lines and exciting the two degenerate resonant modes on an annular uniform impedance ring resonator (UIRR). By attaching a pair of stub perturbations on the diagonal line that is symmetrical with respect to the two feed lines, the UIRR-based dual-mode ring filters are developed and designed using the simple transmission line theorem [2, 3]. In [4], a meander-shaped UIRR is presented in [4] to make up a size-reduced dual-mode ring filter. Recently, a capacitively-loaded slow-wave ring resonator filter with squared shape is reported in [5] to reduce the overall size and broaden the upper stopband. In the meantime, the work in [6] discusses how the transmission zeros can be produced and appropriately allocated on the lower and upper rejection skirts outside the passband by constructing the inductive or capacitive perturbation in a proper diagonal line of a squared UIRR. The rejection skirts with or without transmission zeros are also investigated in the cross-slotted patch dual-mode filters with inductive [7] or capacitive loading [8].

In this work, an improved class of microstrip dual-mode ring filter is proposed by constructing a novel meander-shaped stepped impedance ring resonator (SIRR). Following the works in [4, 9], this proposed SIRR can be expected to have a great capacity in simultaneously achieving the size reduction and harmonic suppression. Our comparative study at first assures us that the concerned 1st spurious resonant frequency (f_1) is largely raised from 3.20 GHz (UIRR) to 5.30 GHz (SIRR), thus exceeding the three times of its fundamental counterpart, i.e., $f_0 = 1.57$ GHz. Then, this SIRR is

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capacitively fed in the two perpendicular locations. In order to tighten the line-to-ring tight coupling, the two opened-end feed lines are readily stretched into the central slits of meander lines as implemented in [4, 8]. Further, the two squared notches are etched out on the corners of a symmetrical or unsymmetrical diagonal line. They are utilized here as a pair of inductive perturbations as studied in [6] to excite the two degenerate resonant modes. The two filter blocks are finally designed and fabricated with and without transmission zeros. Measured results show that the proposed dual-mode filter with the passband of 6.6% at 1.52 GHz achieves the very wide stopband from 1.60 to 5.10 GHz.

2 Meander-shaped stepped-impedance ring resonator

Fig. 1 (a) and 1 (b) depict the layouts of the traditional squared uniform and stepped impedance ring resonators, i.e., UIRR and SIRR, which are driven

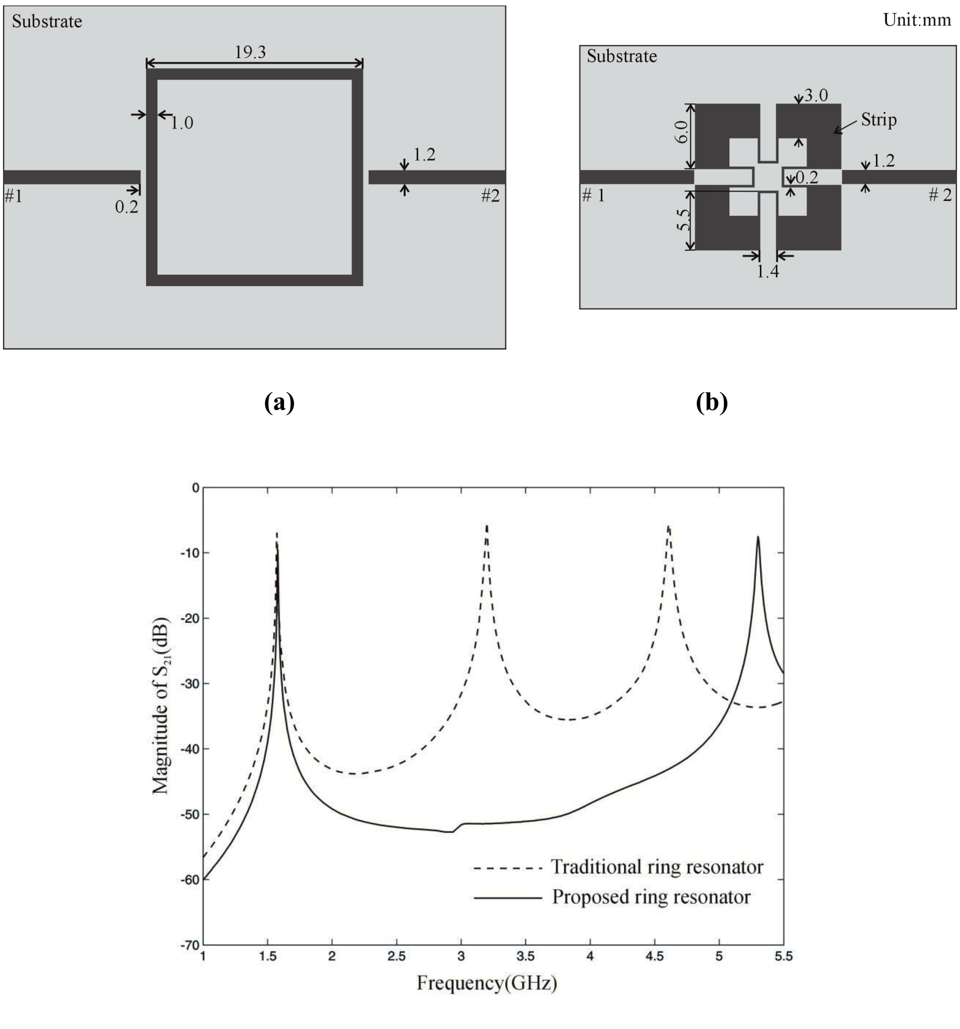

Fig. 1. Layouts and resonance behaviors of the traditional UIRR and proposed SIRR resonator circuits (a) UIRR geometry; (b) SIRR geometry; (c) frequency responses of S_{21}-magnitudes.

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by the two paralleled feed lines via weakly capacitive coupling gaps. In the proposed SIRR, each of the four identical sides is composed of the high-impedance meander line with the strip width of 0.2 mm at the center and the low-impedance strip line with the strip width of 3.0 mm at the two sides around the corners of this squared ring resonator. According to the theorem reported in [9], this SIRR can be expected to effectively control the stopband between the fundamental and the 1st spurious resonant frequencies, i.e., f_0 and f_1, in terms of the impedance ratio of the narrow and wide strip sections in Fig. 1 (b).

In this section, the electrical characteristics of the UIRR and SIRR resonator circuits in Fig. 1 (a) and 1 (b) are numerically simulated using the Agilent Momentum software. In order to comparatively study their distinctive features, these two circuits based on UIRR and SIRR are designed to operate at the same fundamental resonant frequency of $f_0 = 1.57$ GHz by adjusting the strip-line lengths in the four ring sides. In this way, as can be found in Fig. 1 (a) and 1 (b), the overall dimension is significantly reduced from 19.3 mm × 19.3 mm (UIRR case) to 13.4 mm × 13.4 mm (SIRR case), thus achieving the size reduction of about 50% in area. Simulated frequency responses of S_{21}-magnitude of these two resonators are plotted in Fig. 1 (c). In comparison to $f_1 = 3.20$ GHz in the UIRR, the 1st harmonic in the SIRR is largely increased to 5.30 GHz that is beyond the three times of f_0, i.e., $f_1/f_0 = 3.37$. In the next section, this enlarged ratio factor is utilized to implement an improved class of dual-mode ring filters with broadened stobpand.

3 Proposed dual-mode bandpass filters

The two dual-mode filters based on the SIRR are constructed by etching out a pair of squared notches on the two faced corners along either of the diagonal lines as illustrated in Fig. 2 (a) and 2 (b), respectively. The two perpendicular feed lines with open ends are at first simultaneously stretched into the slits

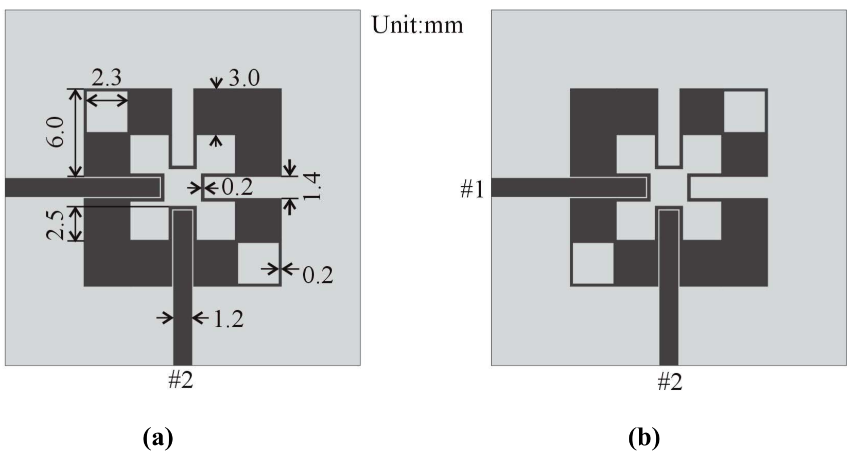

Fig. 2. Layouts of the two SIRR-based dual-mode filters. (a) Type-A: with transmission zeros; (b) Type-B: without transmission zeros.

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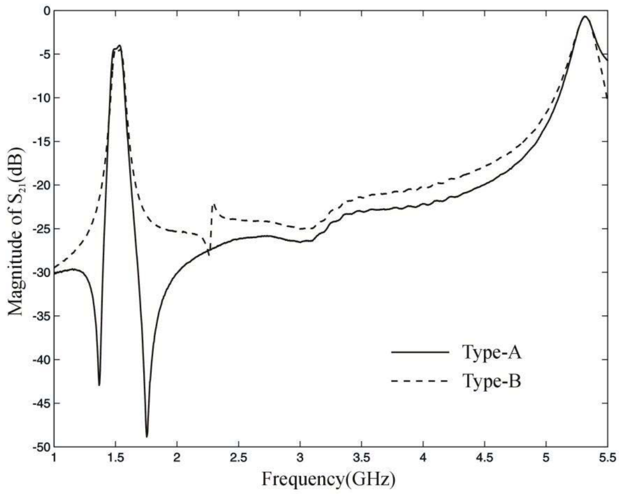
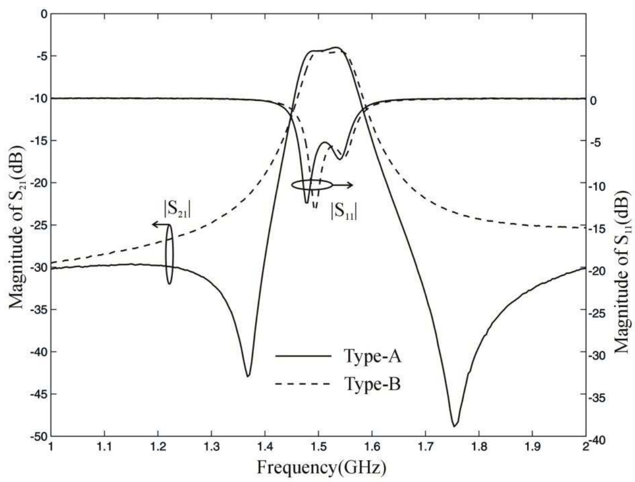
of the meander strip sections at center to realize the tightened line-to-ring coupling [2, 8]. The paired notches are then formed along the diagonal line that is perpendicular or parallel to the symmetrical plane of the two feed lines. Different from the open-end stub as discussed in [2, 3, 4, 5], the notch itself in the corner actually behaves like an equivalent series-inductive element. As such, following the theorem in [6], we can intuitively understand that the transmission zeros on the lower and upper rejection skirts of the dominant passband are existed in the Type A and not in the Type B.



(a)



(b)

Fig. 3. Measured scattering parameters of the two fabricated dual-mode filters: (a) in the wide band; (b) in the narrow band.

Using the Momentum software, the two proposed dual-mode filters are further optimally designed towards minimizing the return loss within the dominant passband. The used dielectric substrate is the Roger's RT/Duroid 6010 with the permittivity of $\varepsilon_r = 10.8$ and thickness of $h = 1.27$ mm. The

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two prototype filter circuits are then fabricated in order to provide an experimental confirmation on the actual emergence of such a widened upper stopband.

Fig. 3 (a) and 3 (b) depict the measured results of these two fabricated filters in the narrow and wide frequency regions, respectively, to give a comparative illustration of their filtering behaviors. From Fig. 3 (a), it can be seen that the 1^{st} spurious passband appears around 5.30 GHz that is 3.49 times of the dominant passband at 1.52 GHz in both cases. As such, these two filters can really suppress the 1^{st} two parasitic harmonics as existed in the UIRR-based dual-mode filters [2, 3, 6], resulting in significantly broadening the concerned upper stopband. The measured results in Fig. 3 (b) further give us the close view on the electrical performance around the dominant passband. As the paired notches in the Type A are formed on the left-top and right-bottom corners as shown in Fig. 2 (a), the two transmission zeros can be observed outside the passband. As such, these two zeros lead to the better improvement of the bandpass behaviors with sharper rejection skirts in the lower and upper stopbands as compared to that of the other filter (Type B). Within the dominant passband of 6.6% at 1.52 GHz, the measured magnitudes of S_{11}- and S_{21}-parameters for the two initial prototype filters achieve about 5.5 and 4.5 dB, respectively.

4 Conclusions

In this work, a meander-shaped stepped-impedance ring resonator (SIRR) is proposed to explore an improved class of dual-mode filters with miniaturized size and broadened stopband. The numerical results demonstrate that the 1^{st} harmonic resonant frequency of this SIRR is raised beyond the three times of its fundamental counterpart. The two dual-mode filters are then optimally designed and fabricated. Under the fixed central frequency of the passband at 1.52 GHz, the overall size of this proposed filter find to be tremendously reduced by about 50%. The upper stopband is largely widened with the frequency region from 1.60 to 5.10 GHz. In the future, the unexpected tolerances in the substrate parameters and fabrication will be taken into consideration towards further improving the passband behaviors with large return loss and small insertion loss.

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