A Novel Dual-Mode Bandpass Filter With Wide Stopband Using the Properties of Microstrip Open-Loop Resonator

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***Abstract*—A novel dual-mode microstrip square loop resonator is proposed using the slow-wave and dispersion features of the microstrip slow-wave open-loop resonator. It is shown that the designed and fabricated dual-mode microstrip filter has a wide stopband including the first spurious resonance frequency. Also, it has a size reduction of about 50% at the same center frequency, as compared with the dual-mode bandpass filters such as microstrip patch, cross-slotted patch, square loop, and ring resonator filter.**

***Index Terms*—Dual-mode filter, size reduction, wide stopband.**

I. Introduction

THE USE of dual-mode resonators to realize microwave filters has been known for years [1]–[4]. Compact, high-performance microwave bandpass filters are highly desirable in wireless communications systems, such as satellite and mobile communications systems. Consequently, dual-mode filters have been widely used in wireless communications systems because of their advantages in applications requiring high quality narrow-band microwave bandpass filters with features such as small size, low mass, and low loss. Many authors [2], [3] have proposed the dual-mode loop and patch resonators for miniaturization of the dual-mode microstrip filters. However, the present dual-mode filter configurations occupy still a fairly large circuit area, which is not quite suitable for wireless communications systems where the miniaturization is an important factor. Therefore, it is desirable to develop new types of dual-mode microstrip resonators not only for offering alternative designs, but also for miniaturizing filters.

On the other hand, modern wireless communication systems require the bandpass filters having out-of-band spurious rejection performance as well as good in-band performance. Resonators with good spurious-free performance are needed to meet the out-of-band requirements. Such a resonator, named a microstrip slow-wave open-loop resonator, has been proposed to introduce various planar bandpass filter configurations [5]. Microstrip open-loop resonators have a wide stopband resulting from the dispersion effect, as well as compact size, due to the slow-wave effect. In this letter, we present a novel dual-mode microstrip filter that uses degenerate modes of a microstrip loop resonator. The microstrip loop resonator consists of four identical arms and each arm is a microstrip open-loop element. The new filter structure has not only a smaller size, as compared with the other dual-mode microstrip filters [2]–[4], [6], but also a wide stopband, including the first spurious resonance frequency due to the dispersion effect resulted from frequency-dependent velocity.

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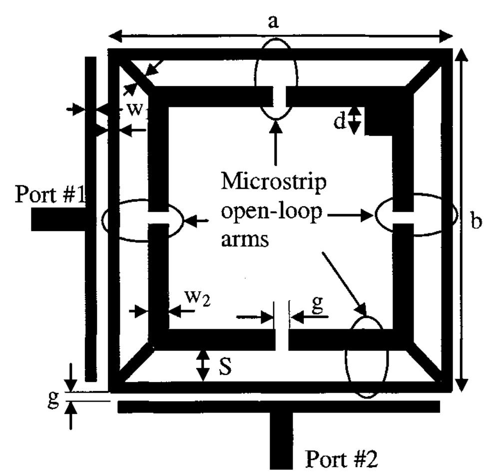
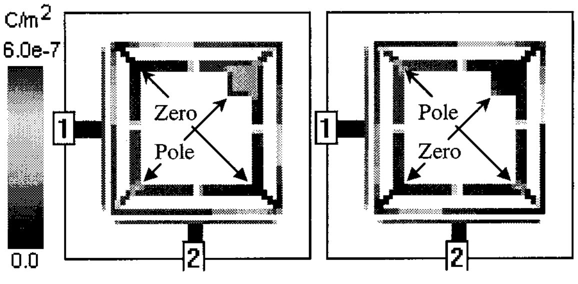


Fig. 1. Proposed dual-mode microstrip filter.

II. Dual-Mode Resonator

Fig. 1 shows the new dual-mode microstrip loop resonator, which is the basic element for the proposed dual-mode filter with a wide stopband. The microstrip loop resonator consists of four identical arms with a small square patch attached to an inner corner of the square loop. The degenerate modes are excited and coupled to eachother due to the square perturbation element within the loop resonator. To simplify our description, the degenerate modes are named as Mode-I and Mode-II. Each of the identical arms may be considered a microstrip open-loop element. Although each arm of the proposed dual-mode resonator is an open-loop element, it can be shown that the two fundamental degenerate modes correspond to TM^z_{100} and TM^z_{010} modes in a square patch resonator (where z is perpendicular to the ground plane), as described in [2]. Fig. 2 shows the charge density patterns computed using a full-wave EM simulator [7], when the square perturbation is added ($d \neq 0$). Indeed, it can be clearly observed from these patterns that two degenerate modes correspond to TM^z_{100} and TM^z_{010} modes in a square patch resonator, as mentioned above. The locations of poles and zeros of Mode-I for $d \neq 0$ are rotated by 90° from those of Mode-II.



(a) (b)

Fig. 2. Simulated charge density at the resonance frequencies of degenerate modes for $d \neq 0$. (a) Mode-I ($f = 1.53$ GHz). (b) Mode-II ($f = 1.57$ GHz).

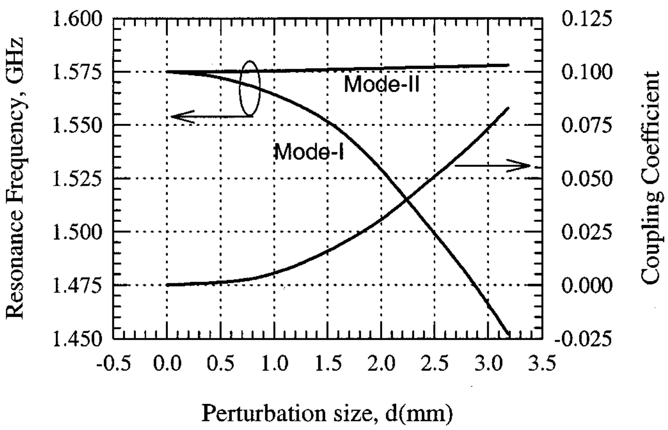


Fig. 3. Simulated coupling coefficient and two resonance frequencies of degenerate modes against the perturbation size, where the resonator dimensions are $a = b = 14$ mm, $S = 1.2$ mm, $g = 0.4$ mm, $d = 1.2$ mm, $w_1 = 0.4$ mm, and $w_2 = 0.8$ mm.

As the coupling between degenerate modes influences these modes differently, there is a split in their resonance frequencies. To observe the mode splitting, the dual-mode resonator has been simulated using a full-wave EM simulator [7] with different perturbation size d. Fig. 3 shows the simulated split resonance frequencies of these two modes of the loop resonator with different perturbation size. As can be seen from the figure, the split between the modes also increases as the perturbation size d increases. Without the perturbation ($d = 0$), only the single mode is excited and, consequently, neither splitting of the resonance frequency nor bandpass response has been observed from our simulations. This situation can easily be seen from simulation results in Fig. 3. In addition, the coupling coefficient between these modes can be computed using the relationship between the split in the resonance frequency of two modes and the coupling [5]. The coupling coefficient as a function of the perturbation size is shown in Fig. 3.

III. Dual-Mode Filter

The dual-mode microstrip bandpass filter was fabricated on an RT/Duroid substrate having a thickness of 1.27 mm and a relative dielectric constant of 10.2. The filter was designed and simulated using a full-wave EM simulator [7]. The filter dimensions are $a = b = 14$ mm, $S = 1.2$ mm, $g = 0.4$ mm, $d = 1.2$ mm, $w_1 = 0.4$ mm, and $w_2 = 0.8$ mm. Fig. 4 shows

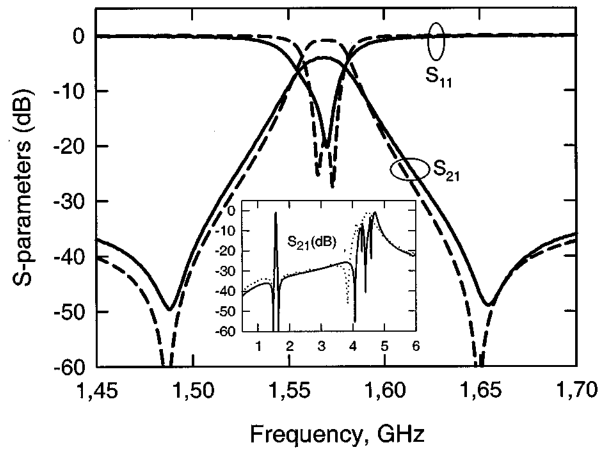


Fig. 4. Simulated (dotted line) and measured (solid line) filter performances. Simulated (solid line) and measured (dotted line) wide-band performances of the proposed dual-mode microstrip filter are shown in the inset.

the simulated and measured frequency responses. The simulated bandwidth is about 1.5%, while the measured bandwidth is 1.8% at the center frequency of 1.57 GHz. The minimum insertion loss is 3.1 dB, higher than the simulated value of 1.5 dB. The loss is due to circuit loss including conductor and dielectric losses. The return loss is better than 15 dB within passband. The simulated and measured results are in good agreement.

On the other hand, the measured wideband response of the dual-mode filter is shown in the inset of Fig. 4. Unlike the other dual-mode microstrip filters, the filter has exhibited a wide stopband with a rejection better than 25 dB up to about 4 GHz. This is because each arm of the dual-mode filter acts as a microstrip open-loop resonator element and microstrip open-loop resonators have a wide stopband, including the first spurious resonance frequency, due to the dispersion effect. Additionally, the center frequency of the filter can be somewhat adjusted by changing the widths w_2 of strips with an open gap. Moreover, the dual-mode filter of 14 $\times$ 14 mm^2 has the smallest size with the size reduction of about 50% as compared with the dual-mode microstrip loop [3], cross-slotted patch [4], and ring resonator filters [6]. Also, the size reduction is 23% against the meander loop resonator filter [2]. The proposed filter has advantages such as narrower bandwidth, smaller size, and wider upper stopband with respect to the dual-mode filter with one coupling gap [8]. The proposed filter has attractive features, including narrower bandwidth, smaller size, and wider upper stopband with respect to the dual-mode filter with one coupling gap [8]. The insertion loss of the proposed filter is somewhat higher against filter in [8], but it can be reduced using the same method as in [8].

IV. Conclusion

A novel dual-mode microstrip square loop resonator has been proposed using the slow-wave and dispersion effects of the microstrip slow-wave open-loop resonators. A dual-mode bandpass filter with a 1.8% bandwidth at the center frequency of 1.57 GHz has been designed and fabricated to demonstrate the application of the proposed loop resonator for designing the compact microstrip filters. The proposed dual-mode microstrip filter has a wide stopband, including the first spurious resonance frequency, due to the dispersion effect. Also, it has a size reduction of about 50% with respect to the dual-mode microstrip patch, cross-slotted patch, square loop, and ring resonator filter, and 23% against the meander loop filter at the same center frequency.

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