A Reduced-Size Dual-Mode Bandpass Filter With Capacitively Loaded Open-Loop Arms

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***Abstract*—A novel type of dual-mode microstrip bandpass filter using degenerate modes of a dual-mode microstrip square loop resonator with capacitively loaded open-loop arms is proposed. Such a dual-mode bandpass filter with a 0.75% bandwidth at the center frequency of 1.603 GHz is designed and fabricated to demonstrate the design of reduced-size microstrip filters. It is shown that the proposed filter has a size reduction of about 59% 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*—Capacitive loading, dual-mode bandpass filter, size reduction.**

I. INTRODUCTION

THE use of dual-mode resonators to realize microwave filters has been known for years [1]–[4]. A compact and 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], [4] have proposed the dual-mode loop and patch resonators for miniaturization of the dual-mode microstrip filters. Recently, a dual-mode loop resonator using the properties of microstrip open-loop resonator has been proposed for miniaturization of the microstrip dual-mode filters [7]. 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.

In this Letter, we present a novel dual-mode microstrip filter that uses degenerate modes of a square loop resonator with capacitively loaded open-loop arms. The proposed filter has a smaller size as a compared with the dual-mode microstrip filters. A filter sample of this type was designed and fabricated to demonstrate the design of reduced-size microwave filters.

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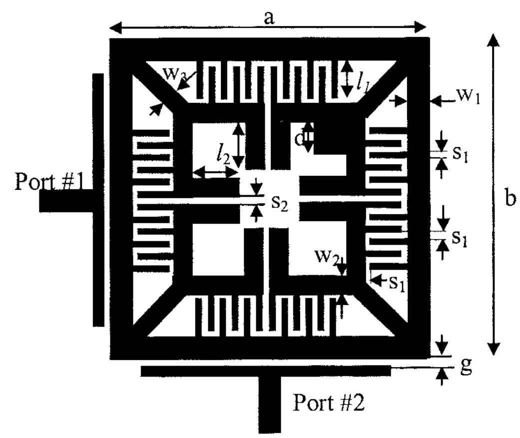

Fig. 1. Proposed dual-mode microstrip filter.

II. DUAL-MODE RESONATOR

Fig. 1 shows the new dual-mode microstrip loop resonator, which is basic element for the proposed dual-mode filter. The microstrip loop resonator consists of the four capacitively loaded identical arms. The capacitive loading is obtained using interdigitated fingers inside each open-loop arm of the resonator, and coupled strips extended toward the circuit center and attached to the open-ends of each arm. Moreover, the resonance frequency of the dual-mode resonator can be tuned by changing the number of capacitive interdigitated fingers, the lengths l_2 of coupled strips and the gap s_2 between the coupled strips.

Input and output ports are spatially separated at 90° in electrical length, and a small square patch as a perturbation element is attached to an inner corner of the square loop. Without perturbation element $(d = 0)$, only a single mode is excited. Fig. 2(a) shows the charge density pattern of the excited resonance mode computed using a full-wave EM simulator [6]. It can be clearly observed from this pattern that the two zeros are located in the middle of the top and bottom arms, the two poles are located in the middle of the left and right arms. If the excitation port is changed to port 2, the charge density pattern is rotated by 90°. This situation describes the degenerate modes, as mentioned in [3], and is illustrated in Fig. 2(b).

The degenerate modes are excited and coupled to each other due to the square perturbation element within the dual-mode resonator. To simply our description, the degenerate modes are named as Mode-I and Mode-II. Each of the four identical arms may be considered as a microstrip capacitively loaded open-loop element. Although each arm of the proposed

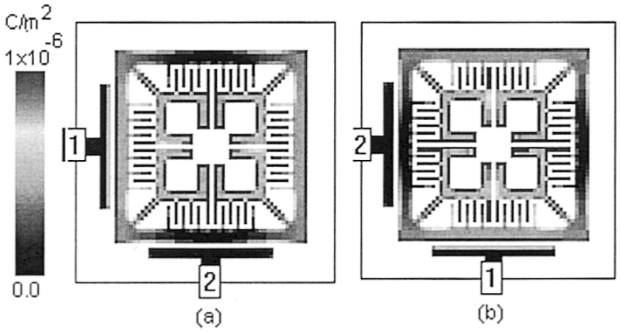

Fig. 2. Simulated charge density at the resonance frequency $f_r = 1.605$ GHz of a single mode for $d = 0$ (a) when the excitation port is port 1 and (b) when the excitation port is changed to port 2.

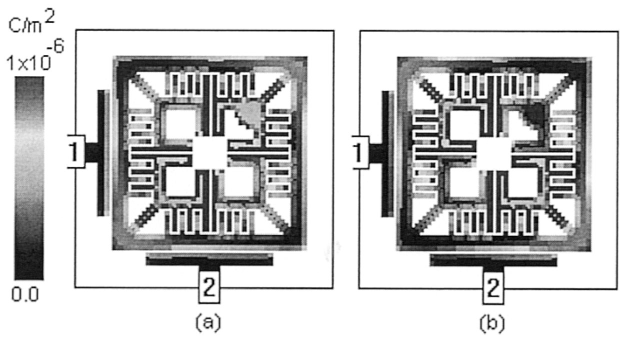

Fig. 3. Simulated charge densities at the resonance frequencies of degenerate modes for $d \neq 0$ (a) Mode-I ($f = 1.591$ GHz) (b) Mode-II ($f = 1.607$ GHz).

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. 3 shows the charge density patterns computed using a full-wave EM simulator [6], 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 (at right-upper corner and left-lower corner) and zeros (at left-upper corner and right-lower corner) of Mode-I for $d \neq 0$ are rotated by 90° from those of Mode-II.

To observe the mode splitting, the dual-mode resonator has been simulated using a full-wave EM simulator [6] with different perturbation size d. Fig. 4 shows the simulated split resonance frequencies of these two modes of the 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 ($d = 0$), since only the single mode is excited, 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. 4. 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 [7]. The coupling coefficient as a function of the perturbation size is shown in Fig. 4.

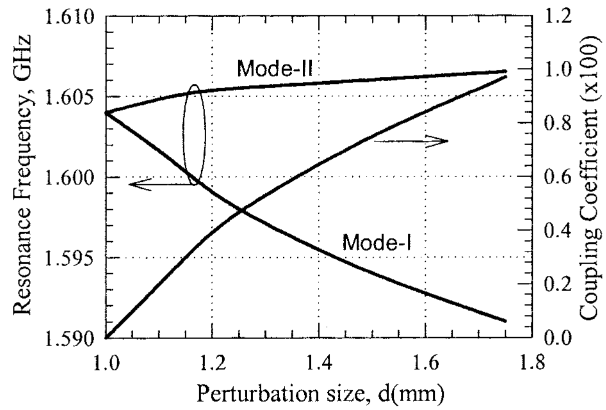

Fig. 4. Simulated coupling coefficient and two resonance frequencies of degenerate modes against the perturbation size, where the resonator dimensions are $a = b = 12.75$ mm, $w_1 = 1.0$ mm, $w_2 = w_3 = 0.75$ mm, $s_1 = 0.25$ mm, $l_1 = 1.5$ mm, $s_2 = 0.25$ mm, $l_2 = 1.75$ mm, and $g = 0.25$ mm.

III. Dual-Mode Filter

The dual-mode microstrip bandpass filter was designed and fabricated on an RT/Duroid substrate having a thickness of 1.27 mm and a relative dielectric constant of 10.2. The filter dimensions are $a = b = 12.75$ mm, $d = 1.2$ mm, $w_1 = 1.0$ mm, $w_2 = w_3 = 0.75$ mm, $s_1 = 0.25$ mm, $l_1 = 1.5$ mm, $s_2 = 0.25$ mm, $l_2 = 1.75$ mm, and $g = 0.25$ mm. The filter was simulated using a full-wave EM simulator [6]. Fig. 5 shows the simulated and measured frequency responses. The simulated bandwidth is about 0.75%, while the measured bandwidth is 1.4% at the center frequency of 1.603 GHz. The minimum insertion loss is 2.9 dB, higher than the simulated value of 0.5 dB. The loss is mainly due to circuit loss including conductor, dielectric, and radiation losses. The return loss is better than 12 dB within passband. Although there are some differences between the simulated and measured results due to the fabrication tolerances, and the nonideal situations of the experimental medium since the filter was measured in the open, the simulated and measured results are in good agreement. The electric field between the capacitive fingers and between a pair of coupled strips directed toward circuit center becomes stronger since the gaps s_1 and s_2 are smaller than the substrate thickness h, and this causes an increase in the radiated fields. As a result, the radiation loss caused by capacitive fingers inside open-loop arms and coupled strips increases the bandwidth of the proposed filter, as well as the insertion loss.

Unlike the wide stopband of the dual-mode microstrip filter with open-loop arms [7], the proposed filter has exhibited a spurious passband at 3.1 GHz. This is because each open-loop arm of dual-mode filter is loaded as capacitive fingers inside open-loops and coupled strips directed toward circuit center. However, the dual-mode filter has an advantage that its center frequency can be adjusted by changing the number of capacitive fingers, the lengths l_2 of capacitive strips, and the gap s_2 between capacitive strips. Moreover, the dual-mode filter of 12.75×12.75 mm^2 has the smallest size with the size reduction of about 59% as compared with the dual-mode microstrip

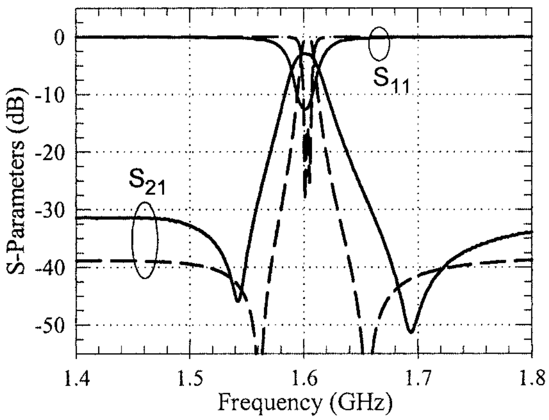

Fig. 5. Simulated (dashed line) and measured (solid line) filter performances.

loop [3], cross-slotted patch [4] and ring resonator filters [5]. Also, the size reduction is, respectively, 36% and 17% against the meander loop resonator filter [2] and microstrip dual-mode filter with open-loop arms [7]. The proposed filter has attractive features, including narrower bandwidth, and smaller size with respect to the other dual-mode filters.

IV. Conclusion

A novel dual-mode microstrip square resonator with capacitively loaded open-loop arms has been proposed. A dual-mode bandpass filter with a 0.75% bandwidth at the center frequency of 1.603 GHz has been designed and fabricated to demonstrate the application of the proposed loop resonator for designing the compact microstrip filters. It has been shown that the proposed dual-mode microstrip filter has a size reduction of about 59% with respect to the dual-mode microstrip patch, cross-slotted patch, square loop and ring resonator filter, and 36% against the meander loop filter at the same center frequency.

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