Microstrip Dual-Mode Bandpass Filter Design with Simultaneous Size Reduction & Spurious Response Suppression

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Abstract **— In this paper, a novel dual-mode bandpass filter using square-loop resonator is proposed. The capacitive stepped impedance inner arm is studied so as to achieve simultaneous size reduction and spurious response suppression for the dual-mode bandpass filter. By introducing this new inner arm at the four inner corners along the square-loop resonator, it is found that an effective spurious response suppression measure at 2nd harmonic and 3rd harmonic can be taken. In order to demonstrate the performance of the proposed filter structure, a prototype filter is designed @ 900 MHz with 1% fractional bandwidth. Significant suppressions up to 37 dB and 31 dB are measured @ 1.8 GHz and @ 2.7 GHz respectively. Moreover, a circuitry size reduction of 40% is achieved when compared with that of the conventional structure.**

Index Terms **— dual-mode filter, size reduction, spurious response suppression.**

I. INTRODUCTION

The microstrip dual-mode bandpass filter permits the compact filter development with narrowband and high-Q for modern telecommunication systems. A number of dual-mode bandpass structures have been proposed over years, they are mainly based on either one wavelength long ring or square-loop resonator [1]-[4]. The dual-mode bandpass filter using square-loop resonator has recently achieved circuitry size reduction whilst transmission zeros can also be easily introduced in the passband proximity to improve the filter selectivity [5]-[7]. But this filter suffers from the problem of spurious responses and these responses are located at the harmonic frequencies of the fundamental frequency. It is also observed that filter compactness can be achieved with more complex inner arms; however the 1st and 2nd spurious responses could be relocated near the passband. This indeed degrades the stopband rejection and becomes an intrinsic performance limitation associated with the wide stopband applications. The unwanted 1st spurious response could be eliminated by cascading bandstop structure but circuitry size increases as well as additional insertion loss are the drawback. Yet, 2nd spurious response suppression is lacking.

In this paper, a new compact dual-mode bandpass filter using square-loop resonator with simultaneous high selectivity, low insertion loss and wide stopband is presented. As compared to the conventional dual-mode filter structure in Fig. 1, a new dual-mode filter topology in Fig. 2(a) is proposed to implement compact spurious response suppressed dual-mode bandpass response. The proposed structure basically resembles the general configuration of the conventional ones except the introduction of the simple stepped impedance arms at the four inner corners along the loop resonator. For this new topology, significant improvement in 1st and 2nd spurious responses suppression as well as miniaturization is realized.

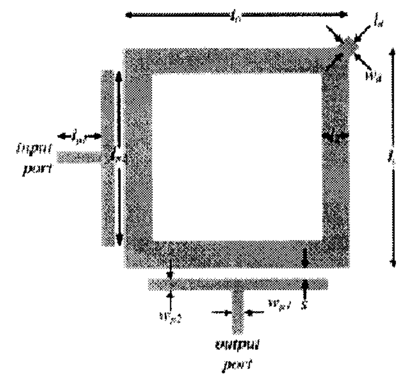

Fig. 1. Conventional dual-mode bandpass filter using stub perturbing outwards.

Besides this introduction, there are three additional sections. To realize simultaneous size reduction and spurious response suppression as the main goal, a new dual-mode bandpass filter based on the capacitive stepped impedance arm is proposed in section II. This bandpass structure takes full advantage of the capacitive loading effect for transmission line miniaturization whilst stepped impedance characteristic is used to relocate the unwanted spurious to higher frequency range. In section III, simulation and experimental results of the proposed structure are presented so as to demonstrate the filter usefulness. Finally, a conclusion is drawn in section IV.

II. DUAL-MODE BANDPASS FILTER USING SQUARE-LOOP RESONATOR WITH CAPACITIVE-SIR ARMS

Recent development of dual-mode bandpass filter using square-loop resonator is to introduce some inner open loop arms with complex geometry so as to achieve additional

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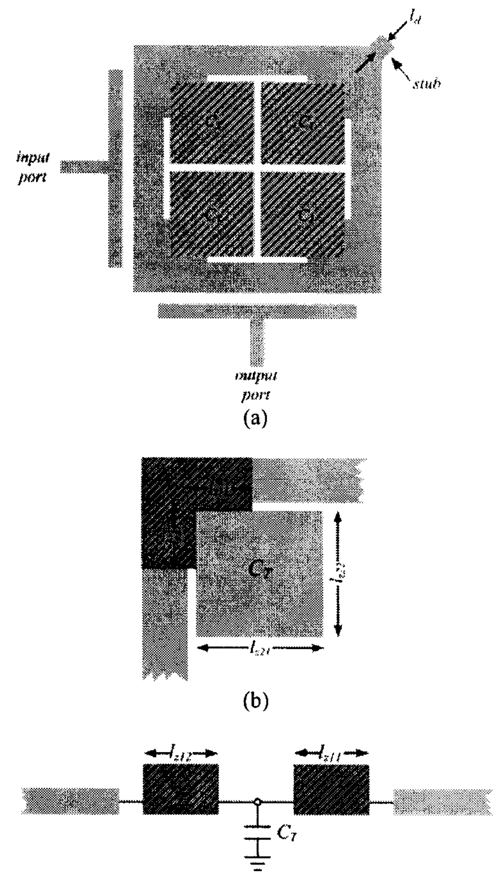

Fig. 2. (a) Proposed dual-mode bandpass filter; (b) capacitive SIR open-loop arm structure at inner corner; (c) equivalent circuit of the capacitive SIR open-loop arm structure.

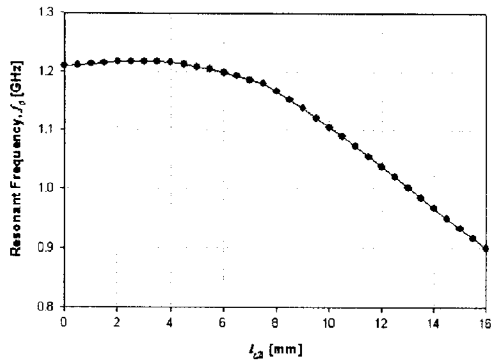

Fig. 3. Resonant frequency variation vs the capacitive loading dimension l_{z2i} (i = 1, 2).

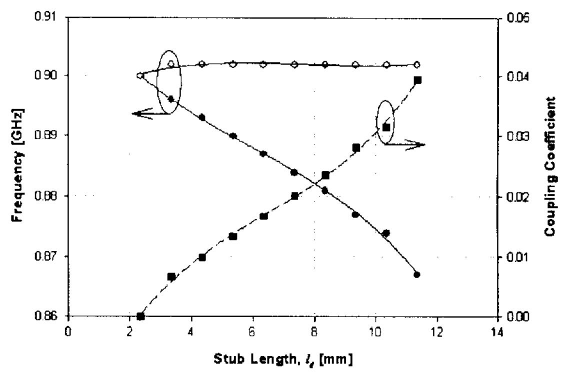

Fig. 4. The two degenerate modes' frequencies and their coupling coefficients (—●— f_1; — ○ — f_2; — ■ — coupling coefficient).

capacitive coupling for size reduction. However, the pattern of these inner open loop arms is complicated and sensitive in fabrication. To overcome the above problem, the proposed topology as shown in Fig. 2 is implemented with simple inner arm architecture while still achieving simultaneous high selectivity, low insertion loss and size reduction. As depicted in Fig. 2(a), this new bandpass filter is designed based on the conventional configuration using the proposed capacitive Stepped Impedance Resonator arm (capacitive-SIR arm) at four inner corners along the resonator loop. The arm is used to provide the necessary coupling for selectivity improvement and size miniaturization. Its effect can be modeled by a capacitive loading C_T [8]. In addition, the capacitive-SIR inner arm is loaded with the square-loop resonator by the sections l_{z11} and l_{z12} as illustrated in Fig. 2(b) and the stepped impedance effect is thus introduced in the resonator. This indeed mainly benefits for the spurious response suppression. The arm can thus be modeled as a SIR transmission line together with the capacitor C_T as shown in Fig. 2(c).

Using MoM based full-wave electromagnetic solver [9], the effect of the filter's fundamental frequency variation against the capacitive loading C_T dimension is studied and plotted in Fig. 3. By varying the length of l_{z21} and l_{z22} as denoted in Fig. 2(b), it implies altering the value of C_T perturbed to the resonator. When the capacitive loading C_T dimension increases, filter's fundamental frequency shifts to lower frequency band. Thus, this allows the lower resonant frequency square-loop resonator to be designed by higher frequency wavelength. By using this capacitive perturbation, a resonator with shorter electrical length can yield the same resonant frequency. As such, the circuitry size reduction is achieved. From Fig. 3, it can be seen that as the length l_{z21} and l_{z22} increases, the resonant frequency shifts to lower band and there is a resonant frequency shift of about 300 MHz as they changes from 0 to 16 mm. The traditional dual-mode filter with resonant frequency at 900 MHz in Fig. 1 is designed on an RO4003 substrate with relative dielectric constant $_r$ = 3.38 and thickness d = 1.524 mm. Its circuitry size is 55.52 × 55.52 mm^2 and can be significantly reduced to as small as 42.40 × 42.40 mm^2 if the proposed capactive arm is used. In addition, the proposed capacitive-SIR arm introduces the step in width along the resonator leading to a major effect of spurious

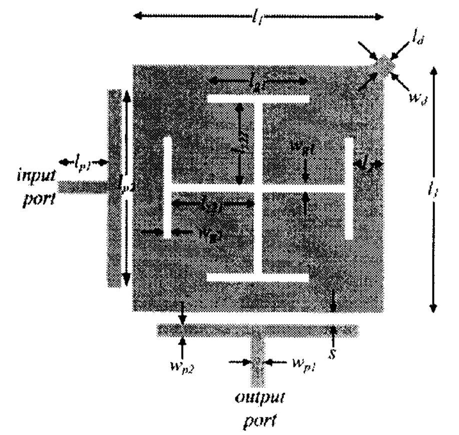

Fig. 5. Proposed dual-mode filter structure with dimensions.

frequencies relocation. Proper choice of the length of l_{z11} and l_{z12} results a wide stopband till the 3rd harmonic frequency of the fundamental ones consequently [10].

Similar to traditional dual-mode bandpass filter of Fig.1, the proposed filter also uses a stub perturbing outwards for the degenerate mode coupling as shown in Fig. 2(a). The degenerate modes are excited and coupled to each other as the length of the perturbation stub l_d increases. The degree of coupling modes depends on l_d, which in return controls the mode splitting. To observe the mode splitting phenomenon, the proposed filter structure is simulated with different stub length. To simplify the illustration, the width of the stub is fixed at 2 mm and the structure is simulated with l_d varies from 2.35 mm to 11.35 mm. The resonant frequency splitting effect and its corresponding coupling coefficient are recorded in Fig. 4. It is found that there is no frequency splitting occur when $l_d < 2.35$ mm. But the resonant frequency splits up into f_1 and f_2 and the frequency splitting increases from 0 to 35 MHz as l_d varies from 2.35 to 11.35 mm. The coupling is in effect as $l_d > 2.35$ mm. When the stub is removed, no perturbation is made and only a single mode is excited; thus, no splitting effect or bandpass response is observed.

III. Simulation & Experimental Results

To demonstrate the performance and spurious response rejection capabilities of the proposed filter structure, this filter's performance is compared with that of the conventional dual-mode bandpass filter. Both of them are designed at center frequency of 900 MHz and they are implemented on an RO4003 substrate with relative dielectric constant $_r$ = 3.38 and thickness d = 1.524 mm. The dimensions of the conventional dual-mode filter and the proposed one are indicated in Fig. 5 and then listed in Table 1. The simulation results of the conventional and the proposed ones are compared in Figs. 6 & 7. Obviously, a wide stopband performance for the proposed dual-mode bandpass filter is observed in Fig. 6 and about 40 dB and 36 dB suppressions

TABLE I
Dimensions of Conventional Dual-Mode Filter and the Proposed Filter (in mm)

l_{p1}	l_{p2}	w_{p1}	w_{p2}	s	l_1
10.00	39.12	2.00	2.00	0.30	43.12
l_2	l_{g1}	$l_{z21,z22}$	$w_{g1,2}$	l_d	w_d
4.00	17.70	16.06	1.00	2.35	2.00

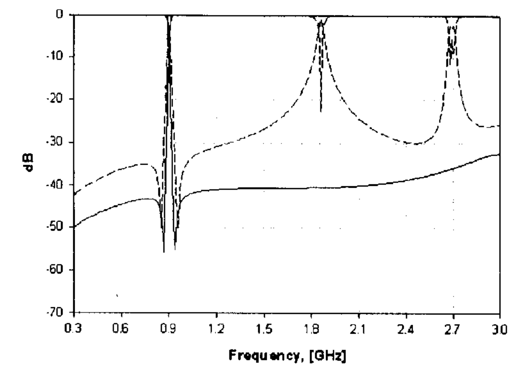

Fig. 6. Comparison of simulated $|S_{11}|$ & $|S_{21}|$ responses of conventional dual-mode and proposed dual-mode bandpass filter (— — — conventional; ——— proposed).

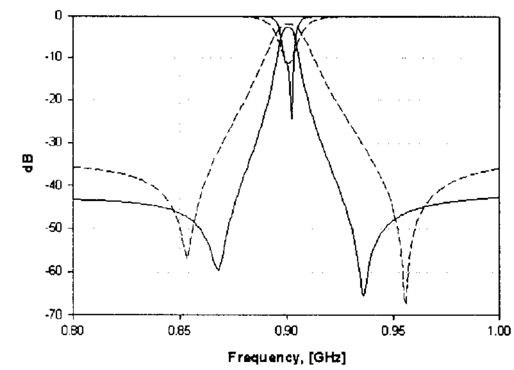

Fig. 7. Comparison of simulated passband $|S_{11}|$ & $|S_{21}|$ responses of conventional dual-mode and proposed dual-mode bandpass filter (— — — conventional; ——— proposed).

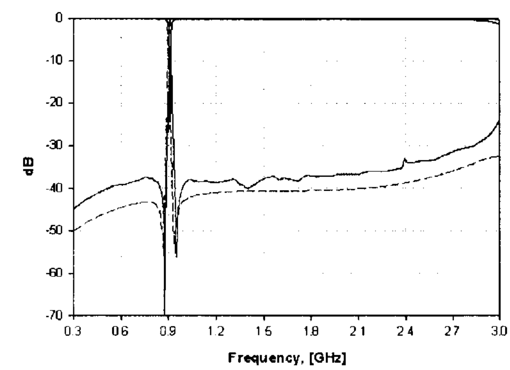

Fig. 8. Comparison of simulated and measured $|S_{11}|$ & $|S_{21}|$ responses of the proposed dual-mode filter (— — — simulated; ——— measured).

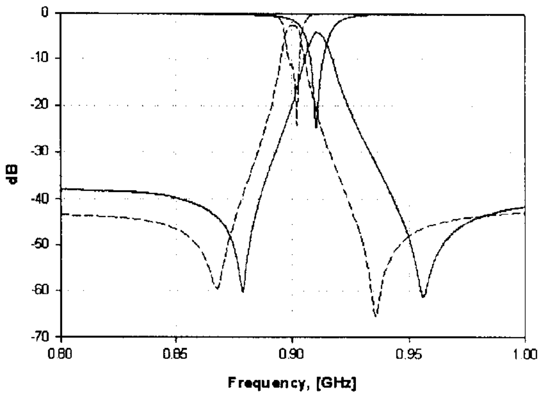

Fig. 9. Comparison of simulated and measured passband $|S_{11}|$ & $|S_{21}|$ responses of the proposed dual-mode filter (— — — simulated; ——— measured).

are reported at the 1st and 2nd spurious frequencies (1.8 GHz and 2.7 GHz) respectively.

From Fig. 7, the fractional bandwidth is computed as 0.78% and has a 48% reduction comparing to that of conventional ones. The proposed filter offers a good matching of 24 dB and the insertion loss is 2.8 dB. This loss is mainly due to the conductor loss. This novel dual-mode bandpass filter is also fabricated on the same substrate. The experimental result shown in Figs. 8 & 9 proves the superb performance of the proposed filter. The experimental results agree with the simulated ones. The center frequency is recorded at 910 MHz and the fractional bandwidth is thus calculated as 1%. The spurious response suppression @1.8 GHz is around 37 dB whilst the 31 dB suppression @2.7 GHz. The matching is kept as good as 23 dB and the minimum insertion loss is measured as 4.2 dB. The photo of the fabricated filter measured with 42.40 × 42.40 mm^2 is shown in Fig. 10 and around 40% size reduction is achieved by this prototype comparing to that in the conventional dual-mode filter.

IV. Conclusion

In this paper, a dual-mode bandpass filter is proposed with the advantages of low-loss, narrow bandwidth, miniaturized size and ability to suppress 1st and 2nd spurious responses. In order to verify this approach practical, a 900 MHz microstrip filter is designed and experimentally characterized in reference to conventional ones. It is reported that the proposed filter offers 37 dB and 31 dB suppressions at 2nd and 3rd harmonics. Moreover, this new structure has size reduction up to 40%. By this new design, the traditional dual-mode bandpass filter's performance is improved.

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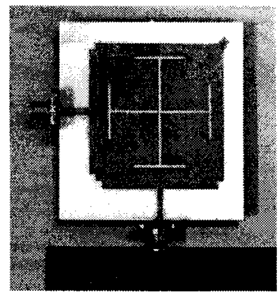

Fig. 10. Photo of the proposed dual-mode bandpass filter prototype.

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