# Extended-Stopband Bandpass Filter Using Both Half- and Quarter-Wavelength Resonators

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***Abstract*—A novel quasielliptic microstrip bandpass filter (BPF) using both half- and quarter-wavelength resonators is proposed. With the quarter-wavelength $(\lambda/4)$ resonators placed in the interstage, the filter spurious passband can be pushed up to 3 $f_0$ where $f_0$ stands for the passband center frequency. To improve the stopband characteristics, a modified stopband-extended filter is implemented, utilizing the multiple transmission zeros placed at specified frequencies to achieve good frequency selectivity and out-of-band rejection. The modified filter provides a 22.5-dB rejection level from 1.14 $f_0$ to 5.2 $f_0$.**

***Index Terms*—Cross-coupled bandpass filter (BPF), extended stopband, half-wavelength resonator, microstrip, quarter-wavelength resonator.**

## I. INTRODUCTION

MICROSTRIP bandpass filters (BPFs) using distributed-element components are quite popular in modern communication systems. The design approach associated with coupled-resonator microstrip filters provided in [1] makes the filter simulation procedure become simple and routine. Half-wavelength $(\lambda/2)$ resonators are widely used in designing filters, such as parallel-coupled-line filters [2], open-loop coupled-resonator filters [3], etc. However, the filters with $\lambda/2$ uniform-impedance resonators have the spurious passbands occurring at $nf_0(n = 2, 3, 4\ldots)$. The filters based on $\lambda/4$ resonators, e.g., the interdigital and combline filters, have been well-established in the literature [4]–[6]. In contrast with the $\lambda/2$-resonator filters, the filters consisting of $\lambda/4$ uniform- impedance resonators possess higher-order harmonics located at $(2n+1)f_0(n = 1, 2, 3\ldots)$.

Among the filters mentioned above, almost all of them suffer from the unwanted passbands associated with the higher-order resonances. Two main approaches have been adopted to eliminate these spurious or parasitic passbands: i.e., either by cascading an additional lowpass filter or by directly suppressing them. The principal drawbacks of cascading a lowpass filter are the increase of circuit size and insertion loss [7]. To avoid these disadvantages, several effective methods were alternatively proposed to suppress the spurious passbands, such as the wiggly-line filter [8], UC-PBG BPF [9], parallel coupled microstrip filter with ground-plane aperture [10], and so on.

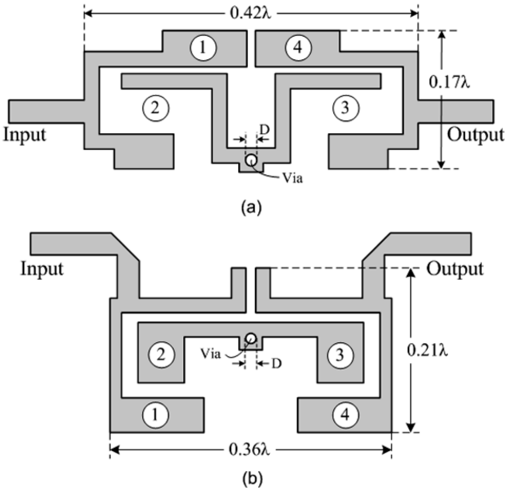

Fig. 1. Layouts of the proposed fourth-order cross-coupled microstrip BPFs using both $\lambda/2$ and $\lambda/4$ resonators, where "D" denotes the via diameter. (a) Basic type. (b) Extended-stopband type.

Nevertheless, none of the studies published have ever tried to simultaneously utilize $\lambda/2$ and $\lambda/4$ resonators to design and implement microwave filters. In this study, a novel microstrip filter using these two kinds of resonators is proposed and fabricated. With proper arrangement, the new filter shows elliptic response thus has sharp selectivity around the passband. Unlike the conventional $\lambda/4$-resonator BPF requiring several vias [11], this proposed filter only uses one via and still exhibits the same response like that using all $\lambda/4$ resonators. In order to suppress the undesired passbands of the proposed filter associated with the higher-order resonances, the open stubs are utilized to create multiple transmission zeros so that a modified stopband-extended BPF may be realized with improved out-of-band rejection.

## II. DESIGN OF THE FILTER USING BOTH AND RESONATORS

Fig. 1(a) shows the basic type of proposed microstrip BPF structure using both $\lambda/2$ and $\lambda/4$ resonators. The resonators 1 and 4 are consisted of identical $\lambda/2$ stepped-impedance resonators (SIRs), and the resonators 2 and 3 are made of identical $\lambda/4$ uniform-impedance resonators (UIRs). Compared with the conventional filters using all resonators of the same form, the proposed filter combines the resonators of different forms in one filter structure. This feature adds the flexibility in designing the coupled-resonator filters.

The resonator 1, the $\lambda/2$ SIR, is folded appropriately to reduce its occupied area. Its impedance ratio $(R_z)$ and length ratio

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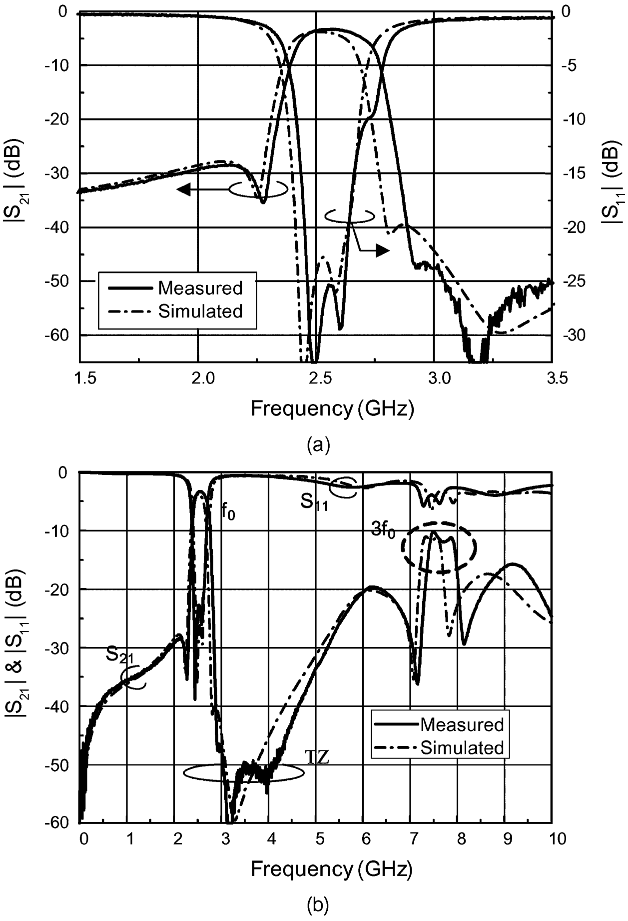
TABLE I
DESIGN PARAMETERS AND SPECIFICATIONS FOR PROPOSED FILTERS

| Filter Layout | FBW | Filter Type | Design Parameters |
|---|---|---|---|
| Fig. 1(a) | 10% | 4-pole<br>Quasi-elliptic,<br>$\Omega_a$=1.8 | $Q_{e1}=Q_{e4}$= 9.9574<br>$M_{12}=M_{34}$= 0.0856<br>$M_{23}$= 0.0786<br>$M_{14}$= - 0.022 |
| Fig. 1(b) | 10% | 4-pole<br>Quasi-elliptic,<br>$\Omega_a$=2.4 | $Q_{e1}=Q_{e4}$= 9.48<br>$M_{12}=M_{34}$= 0.0886<br>$M_{23}$= 0.07446<br>$M_{14}$= - 0.01123 |

(u) [12], [13] are roughly chosen as 0.45 and 0.5 to get the minimum electrical length. The resonator 2 is a $\lambda/4$ UIR in which the short-circuited end is implemented by the grounding via. In Fig. 1(a), the cross electric-coupling is achieved by the gap between open-ends of resonators 1 and 4, while the metallic via connecting to ground shared by resonators 2 and 3 produces the main magnetic coupling required between the two resonators. In addition, the coupling between resonators 1 and 2 is of mixed type. Consequently, a quasielliptic response may be achieved through the arrangement shown in Fig. 1(a).

The basic microstrip filter [Fig. 1(a)] is fabricated on a FR4 board ($\varepsilon_r = 4.4, h = 1$ mm, $\tan\delta = 0.02$). The via diameter is 1 mm. The design parameters and specifications are listed in Table I. This filter is designed for a quasielliptic response with the center frequency $f_0$ at 2.5-GHz, 3-dB-fractional bandwidth (3 dB-FBW) of 10%, and normalized transmission zero frequency $\Omega_a$ of 1.8. Fig. 2 presents the measured and simulated responses. The measured center frequency is at 2.627 GHz, the measured 3-dB-FBW is about 10.8%, and the minimum insertion loss is 3.38 dB. The reason of center frequency shift lies in the inaccuracy of the line spacing in printed circuit board (PCB) fabrication.

It is worth mentioning that the lower open-stub arm of resonator 1 creates one transmission zero (TZ) located at the higher frequency band thus significantly improving the out-of-band rejection. Evidently, the first spurious passband occurs at about 3 $f_0$ which is the first spurious resonance frequency of resonators 2 and 3. Physically, the spurious response of the whole filter is strongly affected by the resonators placed in the interstage. In the following section, based on the basic-type filter structure in Fig. 1(a), the open and coupled stubs will be utilized to produce multiple transmission zeros to suppress the unwanted passband associated with the first spurious resonance of the $\lambda/4$ resonators 2 and 3.



(a)

(b)

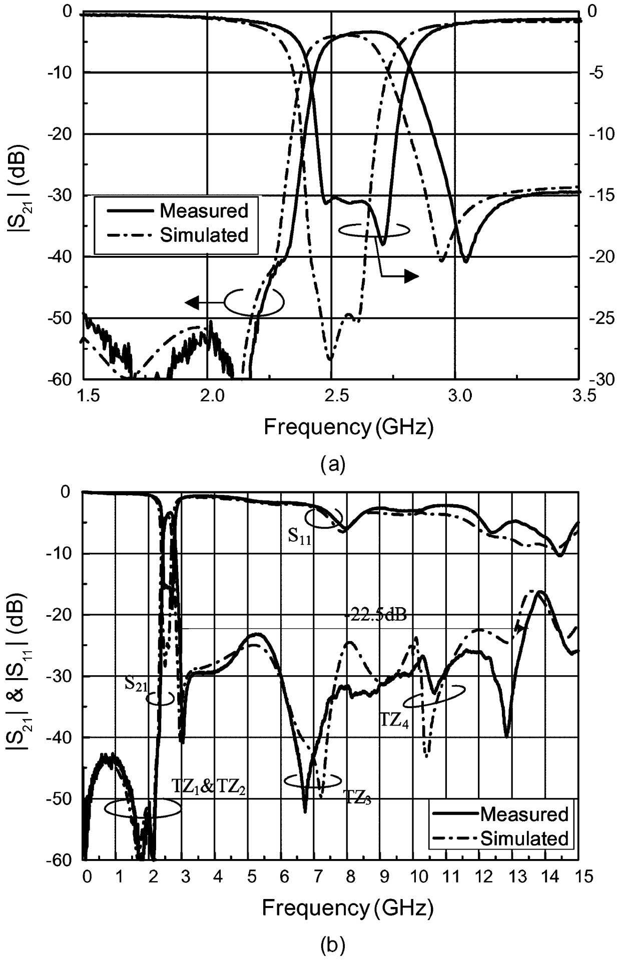
Fig. 2. (a) Narrowband and (b) wideband measured and simulated frequency responses of the basic filter in Fig. 1(a).

## III. DESIGN OF THE STOPBAND-EXTENDED FILTER

The basic-type filter [Fig. 1(a)] using both $\lambda/2$ and $\lambda/4$ resonators possesses the latent capacity to be modified for spurious suppression. By replacing the two interstage $\lambda/4$ resonators by SIRs and adjusting the impedance and length ratios of these two resonators so as to control the first spurious resonance frequency, the spurious passband of the modified filter may be pushed up to a specified frequency. In addition, the open stubs can be utilized to produce additional transmission zeros. Through appropriate deformation of the structure in Fig. 1(a), two stubs are bended to provide a cross-coupled path between resonators 1 and 4 for quasielliptic response. Besides, the tapped position is chosen to locate the transmission zeros $TZ_1$ and $TZ_2$ in the lower band.

Fig. 1(b) shows the layout of the stopband-extended filter modified from the basic-type filter in Fig. 1(a) and fabricated on the same FR4 board. The design parameters and specifications are also listed in Table I. The via diameter is 1 mm. The $R_z$ and u of the two $\lambda/4$ SIRs are set as 0.48 and 0.45, thus the first higher-order resonance is moved up to 10.36 GHz (4.14 $f_0$). The measured and simulated frequency responses are both illustrated in Fig. 3. The measured center frequency $f_0$ is at 2.573 GHz, the 3-dB-FBW is about 10.5%, and the minimum insertion loss is 3.3 dB. The modified filter has a size of only $0.36\lambda \times 0.21\lambda$.

Note that there are four extra transmission zeros appearing in both sides of the passband in addition to the two near the passband edge due to the cross-coupling. These four transmission zeros not only improve the selectivity but also widen the stopband. The first and second transmission zeros ($TZ_1$ and $TZ_2$) located at 1.76 GHz and 2.16 GHz result from the lower and upper arms of resonator 1 which behave like $\lambda/4$ open stubs at those frequency. The lower arm of resonator 1 shorts the signal to ground again at its first higher-order resonance frequency, thereby creating the third transmission zero $TZ_3$. In addition to providing two cross-coupled transmission zeros for quasielliptic response, the length of the two bended coupled



(a)

(b)

Fig. 3. (a) Narrowband and (b) wideband measured and simulated frequency responses of the extended-stopband filter in Fig. 1(b).

stubs also controls the position of the fourth transmission zero $TZ_4$ (10.71 GHz). Since the first higher-order resonance of resonators 2 and 3 is pushed up to 10.36 GHz (4.14 $f_0$) which is near the $TZ_4$, this spurious passband may be effectively suppressed. With the aid of the transmission zeros $TZ_3$ and $TZ_4$, the stopband provides roughly 22.5-dB rejection level extending from 2.938 to 13.36 GHz (1.14 $f_0$ to 5.2 $f_0$). Obviously, these stub-inherent transmission zeros can be easily controlled for required filter performance.

The similarity transformation [14] proposed recently can be adopted to transform the electric cross coupling into magnetic. Though both kinds of cross coupling possess similar highpass characteristic which degrades the level of far-band rejection, the transformation indeed provides another implementation possibility for the proposed filter.

## IV. CONCLUSION

In this study, two novel microstrip BPFs using both $\lambda/2$ and $\lambda/4$ resonators have been proposed. The basic-type filter uses only single via to obtain similar center passband and spurious response of the conventional interdigital and combline filters which use four vias. The spurious passband of the proposed basic-type filter can be controlled by simply adjusting the impedance and length ratios of the $\lambda/4$ resonators. By modifying the structure of basic-type filter, an extended- stopband BPF has been further implemented, which can even push the spurious passband up to 13.36 GHz (5.2 $f_0$). With a suitable adjustment of multiple transmission zeros, the frequency selectivity and out-of-band rejection of the modified filter have been significantly improved. The modified filter using both $\lambda/2$ and $\lambda/4$ resonators with extended stopband is particularly suitable for the modern wireless communication system.

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