

## MICROSTRIP BANDPASS FILTERS USING END-COUPLED ASYMMETRICAL STEP-IMPEDANCE RESONATORS FOR WIDE-SPURIOUS RESPONSE

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**Abstract**—This paper proposes asymmetrical step-impedance resonators bandpass filters (ASIRs) for suppressing a wide stopband, ensuing in size reduction and ease of fabrication. The filters have been designed at the operating frequency around 2.0 GHz using half- and quarter-wavelength asymmetrical step-impedance resonators. The concept of existent odd- and even-mode characteristics is used to improve the proposed filter structure. The filter can not only suppress the unwanted signals more than  $10f_0$ , but also produce low passband insertion loss and high return loss. A good agreement is obtained between the simulation and measurement results.

### 1. INTRODUCTION

Besides high selectivity, low passband insertion loss, simple design and implementation, the necessary requirement of bandpass filters for wireless communication systems is wide stopband characteristics and a compact size [1]. Planar bandpass filters which are fabricated on printed circuit board (PCB) are well-known and attractive because of their suitability for commercial applications [2, 3], but a part of the structure does not obtain a good response although its dimension is small [4]. Traditionally, microstrip step-impedance resonator structure, its impedance ratio less than 1, is favorable employed in RF/microwave filter circuits in order to improve upper stopband performances by shifting the first resonance frequencies away from the resonance frequency. In [5, 6], the parallel and crossed-coupled filters with step-impedance resonator structure has been proposed because

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they can move the harmonics frequencies but their results are not good. To enhance filter performances with spurious passband rejection, the terminated parallel coupled line structure has been proposed to suppress  $2f_0$  and  $3f_0$  harmonic frequencies in [7], but its dimension is considerably large. Squareloop structure, which has a compact size, has been proposed in [8], but its characteristic only obtains the first harmonic suppression [8].

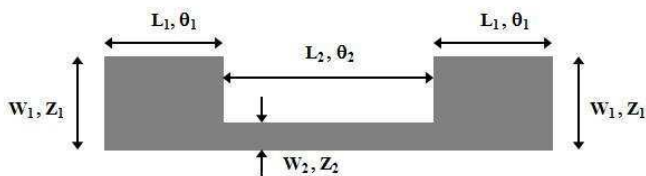
Besides, the two-layer bandpass filter with slot-line structure on ground plane and microstrip line feeds on the other side of the substrate has been also proposed, and resulting frequency selective coupling is utilized to suppress unwanted harmonics. Besides, the coplanar-waveguide-fed microstrip filters with capacitive broadside-coupled structures have been designed for multiple spurious suppressions [9, 10]. Although, both methods can improve the rejection harmonics levels which are extended more than  $5f_0$ , their structures are quite complicated to fabricate. Recently, asymmetrical step-impedance open-loop resonators filters with size reduction have been reported in [11, 12] to suppress unwanted signals in the stopband. Their structures are easy to design and fabricate, so that we acquire this idea for adapting a SIR, in which its impedance ratio is less than 1, to be a half-wavelength and a quarter-wavelength asymmetrical step-impedance resonator (ASIR) bandpass filters with complex size and good wide-stopband characteristics.

In Section 2, an asymmetrical step-impedance resonator is described and simulated for the fundamental response compared with the conventional one. Then, the performance of bandstop characteristic for unwanted signal suppression is also investigated in this section. In Section 3, two bandpass filters will be designed and constructed. Finally, measurement of those proposed filters will be performed and compared with simulation results.

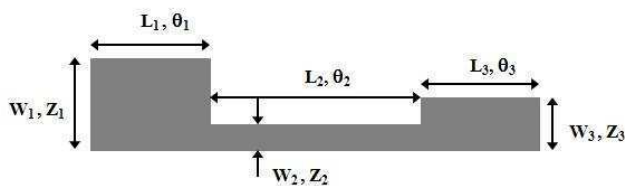
## 2. AN OPTIMIZED ASYMMETRICAL STEP-IMPEDANCE RESONATOR

Normally, a step-impedance resonator consists of three step-impedance segments, and two of them have the same impedance and electrical length at both ends. Step-impedance resonators can be classified into two types as described in [5]. The condition of dimensions of a symmetrical step-impedance resonator is basically given by the impedance ratio of step-impedance resonator,  $K$ . Generally, if the impedance ratio is more than 1, the harmonics responses will swing near the center frequency. In the contrast, if the impedance ratio is less than 1 as shown in Fig. 1(a), the harmonics responses will be

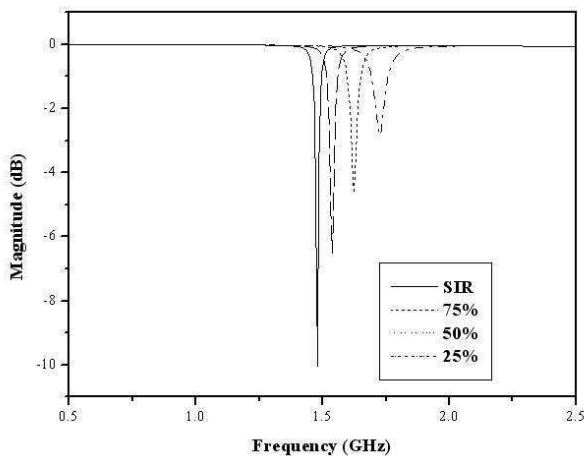
shifted away from the center frequency, so that this characteristic is preferred to be applied to a filter.



(a)



(b)



(c)

**Figure 1.** (a) The symmetrical SIR. (b) The asymmetrical SIR. (c) Frequency response  $S_{11}$  of the asymmetrical structure in any range of  $W_3$ .

As proposed in [11,12], the asymmetrical open loop resonator structure can not only reduce size, but also suppress unwanted signals. So we obtain this idea for applying a step-impedance resonator, which

impedance ratio is less than 1, to be an asymmetrical step-impedance resonator as shown in Fig. 1(b). The resonators have been designed on GML 1032 substrate, which has a given relative dielectric constant of 3.2, thickness of 1.524 mm and loss tangent of 0.004 with  $W_1 = 5.8$  mm,  $W_2 = 0.8$  mm,  $L_1 = L_3 = 11$  mm,  $L_2 = 17$  mm. Then an impedance of another segment of capacitive loads,  $W_3$ , is varied. However, the total length of the resonator is still kept  $L_1 + L_2 + L_3$  less than  $\pi$ . The resonance responses of this resonator are evaluated by using the full-wave simulator, IE3D [13]. Fig. 1(c) shows the return losses of the uniform SIR and asymmetrical resonators which have been optimized to resonate around 1.5 GHz. It is noticed that when the impedance of the one segment of SIR is changed, its size will be larger than the conventional SIR when it is in the same frequency.

Then how to reduce size is well thought out. As described in [14], folding the asymmetrical structures for decreasing size is used. It is noticed that, when an asymmetrical resonator is being folded with the same dimensions, the frequency response is to be around 2 GHz. So that the folded asymmetrical structure has not only compact size, but the internal coupling between two segments of them is also increasing, and its structure dimension is reduced about half. Besides that the characteristic of a hook feed-line is proposed in [15] which encourages the external coupling. So this idea is adapted with the folded structure, and the frequency response of the proposed structure with a normal feed-line is analyzed as shown in Fig. 2(a) and a hook feed-line as shown in Fig. 2(b). The hook feed-line can encourage the external coupling resulting in the desired frequency more than the normal feed-line as shown in Fig. 2(c). The coupling coefficient  $M_{ij}$  for resonator  $i$  and  $j$  will be extracted from the simulated frequency responses by using

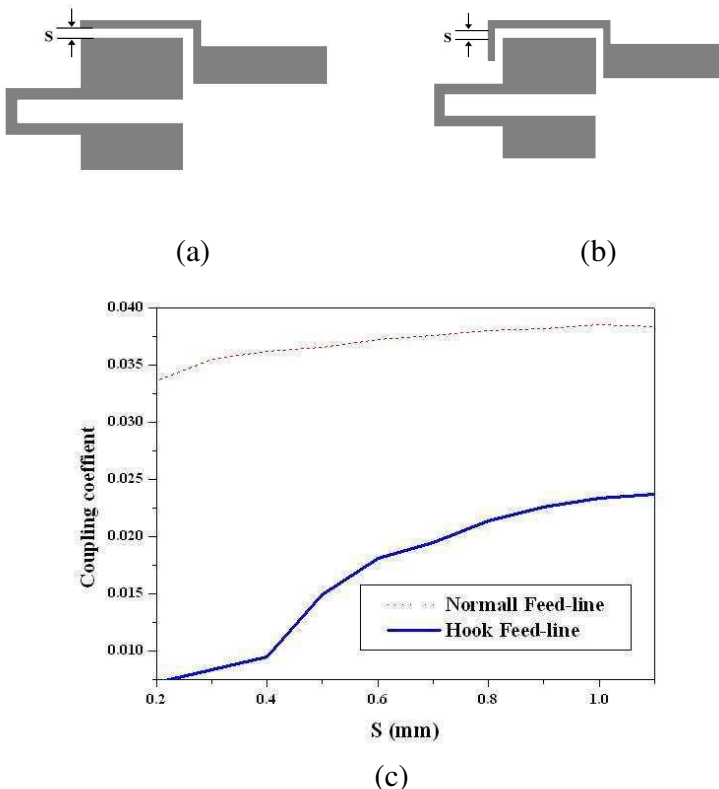
$$M_{ij} = \pm \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \quad (1)$$

where  $f_1$  and  $f_2$  correspond to either even- or odd-mode resonance frequency. The external quality factor may be characterized by

$$Q_e = \frac{f_0}{FBW} \quad (2)$$

where  $f_0$  and  $FBW$  are the resonance frequency and the fractal bandwidth of the input or output resonator when it is externally excited. The external coupling of the proposed filter is 23.81.

It is noticed that the hook feed-line encourages smaller coupling coefficient than the normal feed line. This can give explanation that both structures have the electric and magnetic couplings but the magnetic couplings are principal. Therefore, the coupling property responses are the specification which needs to be considered in choosing



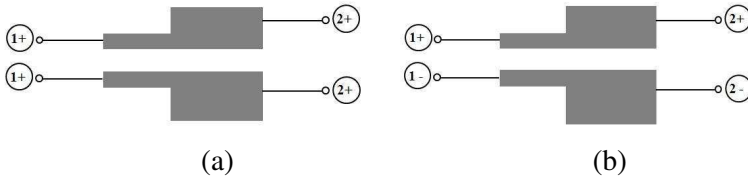
**Figure 2.** The proposed asymmetrical SIR structure with (a) a normal feed-line, (b) a hook feed-line, (c) variation of the coupling coefficient versus the distance  $S$  between the feed-line and resonator.

feed-line. By the way, it can be said that a narrowed filter is designed, and smaller coupling coefficients will be required [16].

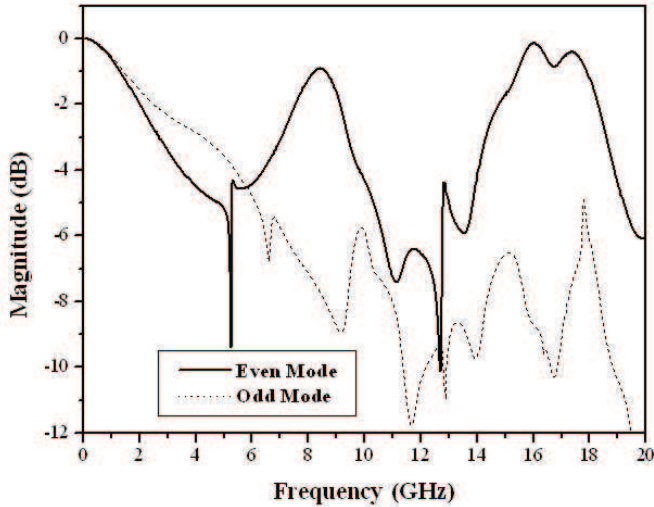
After that we analyze the characteristic response in order to find the reason that an asymmetrical structure can clearly suppress unwanted signals.

### 3. BANDSTOP CHARACTERISTIC FOR SPURIOUS SUPPRESSION

For focusing on an ASIR, the coupled mode analysis is used, and we analyze the folded asymmetrical structure with the excitation of the propagation constant method. The solution of them gives the propagation constants for two modes, which are “c” and “pi” referring



**Figure 3.** The asymmetrical parallel coupled-line with odd- and even-mode excitations in differential two-port for (a) “c-” and (b) “pi-” mode excitations.



**Figure 4.** Frequency response  $S_{21}$  of the asymmetrical structure with odd- and even-mode excitations.

to even- and odd-mode excitations [17]. For c-mode when the two asymmetrical resonators are excited in two ports, four terminals, which are in the same polarity as shown in Fig. 3(a). It is acted as the even-mode. By the way, if two asymmetrical resonators are excited in different polarities of two ports, they are called the pi-mode as shown in Fig. 3(b). Then the IE3D has been employed to evaluate the characteristics of the folded asymmetrical structure by modeling as a differential two-port configuration and excited in the odd- and even-modes, respectively. Fig. 4 shows the resulting frequency notches response ( $S_{21}$ ). The notches of the c- and pi-modes are appended around 5.13, 6.5, 9.2, 12.8 and 16.8 GHz, respectively, close to the harmonic frequency responses of the proposed filter, so that the notch

responses of the c- and pi-modes will undoubtedly involve the proposed resonator resulting in the bandstop characteristics, and then spurious response in the stopband could be achieved.

#### **4. A HALF-WAVELENGTH BANDPASS FILTER EXPERIMENTAL RESULTS**

The first bandpass filter consisting of two asymmetrical step-impedance resonators cascade together is presented. Each resonator is a half-wavelength length. Its dimension is shown in Fig. 5(a). The filter is fabricated on GML 1032. Its structure has a maximally flat passband bandwidth of 90 MHz (or the fractional bandwidth of FBW = 4.5%) at the center frequency of 2 GHz. The filter parameters were obtained in the followings:  $L_1 = 10$  mm,  $L_2 = 0.9$  mm,  $L_3 = 4.4$  mm,  $L_4 = 14.56$  mm,  $W_1 = 5.8$  mm,  $W_2 = 3.34$  mm,  $W_3 = 3.3$  mm,  $W_4 = 6.8$  mm,  $W_5 = 4.9$  mm,  $S_1 = 0.5$  mm,  $S_2 = 0.3$  mm and  $d = 0.3$  mm. Its dimension is  $40.14 \times 32.7$  mm<sup>2</sup>. Nevertheless, two ports are exactly equal to 50 ohm.

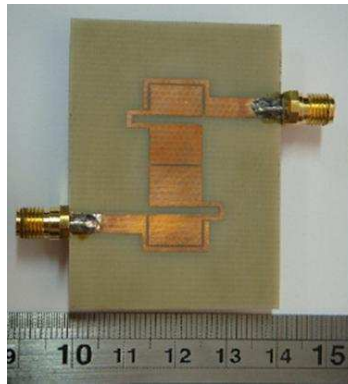
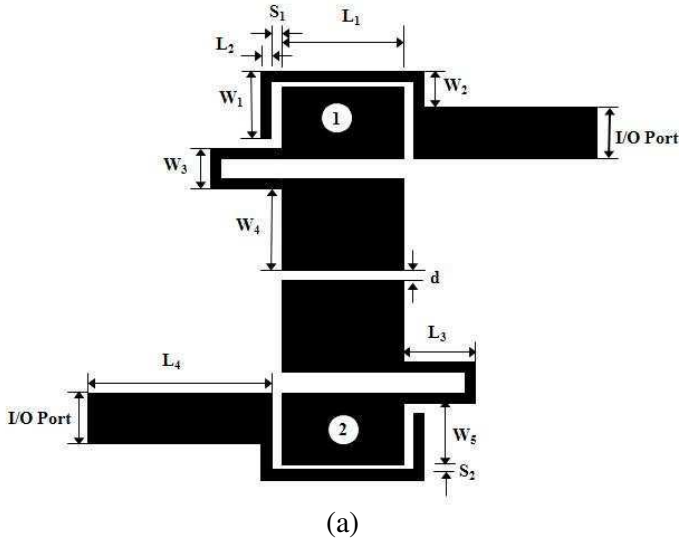
Figure 5(b) shows a photograph of the half-wavelength bandpass filter with wide-spurious response which was then measured on a network analyzer. From the measured data, we found that the frequency response of the proposed filter can produce more than 20 GHz out-of-band rejection as shown in Fig. 6(a). The passband of insertion loss is around  $-2$  dB at 2.01 GHz. We can certainly notice that in the measured results there is a slight deviation in the center frequency and bandwidth, which mainly due to the conductor loss of copper. The passband return loss is  $-28$  dB and can be obtained more than 20 GHz out-of band suppression as shown in Fig. 6(b).

#### **5. A QUARTER-WAVELENGTH BANDPASS FILTER EXPERIMENTAL RESULTS**

However, one of the major problems of the harmonics suppression is a large size of layout. Many ways have been proposed to eradicate it such as the filter with floating ground-plane conductor or a quarter-wavelength structure which is one favorite structure to be reducing size [17–19]. Although a quarter-wavelength structure is very difficult to fabricate, and its response is affected by via holes, its dimension is smaller than a half wavelength structure when comparing in the same frequency response [20]. One limitation of a quarter-wavelength structure is the ability of suppressing unwanted signal that is normally only less than  $3f_0$  [21]. So using a quarter-wavelength structure to be

a bandpass filter is mainly interesting for reducing a dimension and suppressing a harmonic response.

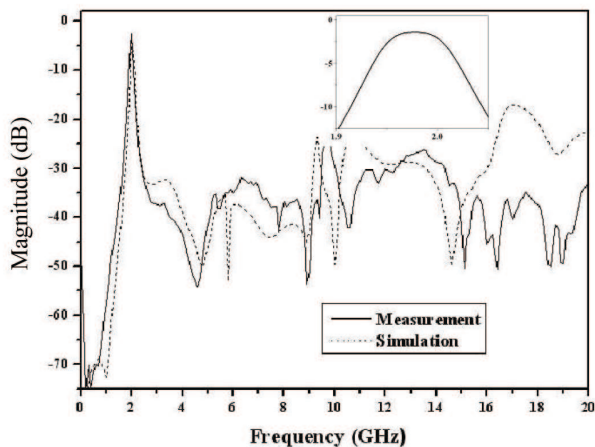
We also take the advantage of the folded asymmetrical and hook structure combining together the same as the half-wavelength filter as described above, but the size of each resonator is reduced to a quarter-wavelength. After that the optimized parameters of



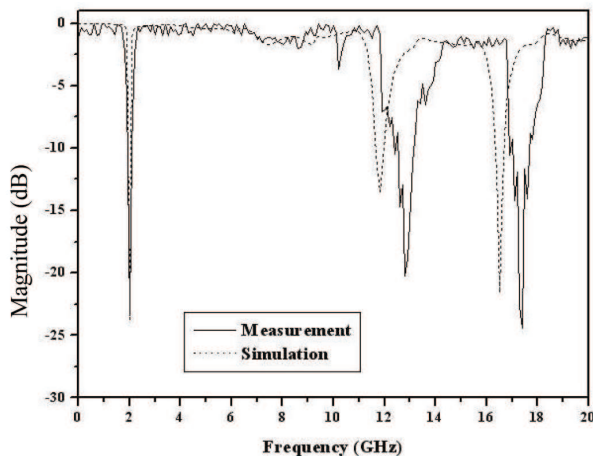
**Figure 5.** (a) Layout of the half-wavelength bandpass filter with wide-spurious response. (b) A photograph of the half-wavelength bandpass filter with wide-spurious response.



the quarter-wavelength as shown in Fig. 7(a) were obtained in the following:  $L_1 = 5$  mm,  $L_2 = 0.2$  mm,  $L_3 = 3.49$  mm,  $L_4 = 0.86$  mm,  $L_5 = 11.47$  mm,  $W_1 = 2.23$  mm,  $W_2 = 4.45$  mm,  $W_3 = 2.5$  mm,  $S_1 = S_2 = S_3 = 0.3$  mm,  $d = 0.3$  mm. Two ports are still equal to 50ohm. A photograph of the quarter-wavelength bandpass filter with wide-spurious response is shown in Fig. 7(b) which was also measured on a network analyzer. The quarter-wavelength bandpass filter has a



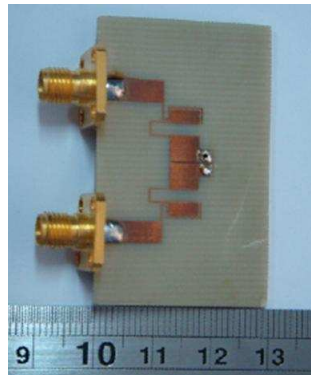
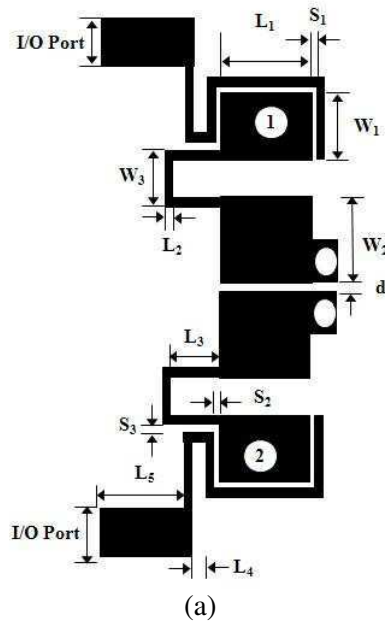
(a)



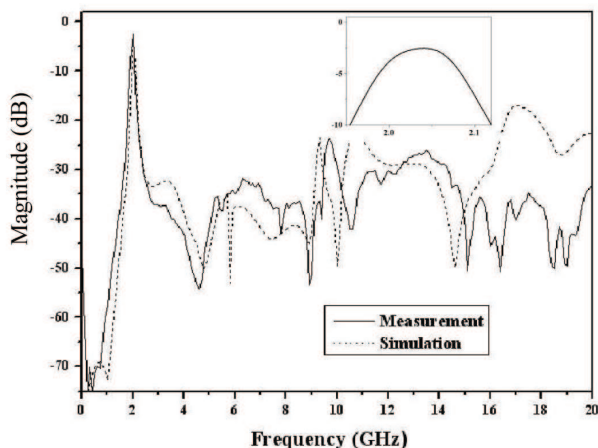
(b)

**Figure 6.** Comparison the response of measured and simulated response of half-wavelength bandpass filter (a) insertion loss, (b) return loss.

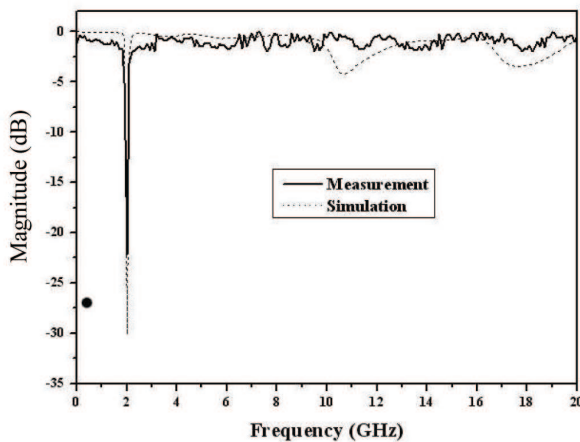
flat passband bandwidth of 60 MHz (or the fractional bandwidth of  $\text{FBW} = 3\%$ ), and the return loss is around  $-24$  dB at the resonance frequency equal to 2 GHz as shown in Figs. 8(a) and 8(b). Its dimension is  $20.28 \times 27.42 \text{ mm}^2$  which is reduced 57.63% compared with a half-wavelength bandpass filter as described in Section 3.1.



**Figure 7.** (a) Layout of the quarter-wavelength bandpass filter. (b) A photograph of the quarter-wavelength bandpass filter.



(a)



(b)

**Figure 8.** Comparison the insertion loss of measured and simulated response of quarter-wavelength bandpass filter (a) insertion loss, (b) return loss.

## 6. CONCLUSION

This paper proposes a modified step-impedance resonator to be an asymmetric structure used for bandpass filter resulting in wide-band stopband characteristics. Asymmetric step-impedance resonators of both open- and short-ends are described. By treating both asymmetric step-impedance resonators with the same fundamental frequency the spurious suppression can be enhanced, and a wide rejection band can

be obtained. The proposed filters have a low insertion loss with a wider upper stopband characteristic that the spurious suppression is better than  $-20$  dB for a frequency range which is more than 20 GHz. The measured responses show good agreement with the simulated results.

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