A NOVEL WIGGLY-LINE HAIRPIN FILTER WITH 2ND SPURIOUS PASSBAND SUPPRESSION

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Abstract **— In this paper, a novel spurious response suppression hairpin bandpass filter is proposed based on the reformulation of the sinusoidal modulation of the wiggly coupled-line. Equal phase velocity can be achieved by the asymmetrical strip width modulation, resulting in significant spurious bandpass suppression. In order to demonstrate the proposed filter performance, two prototype filters are designed @900MHz with 10% fractional bandwidth. From the simulation and experimental results, more than 15dB suppression in the 2nd harmonic spurious passband has been obtained.**

I. INTRODUCTION

In the RF front-end of a modern communication system, bandpass filters with wide stopband and high selectivity are usually required. Over the past 30 years, the microstrip parallel-coupled filter has been one of the most commonly used planar filters because of its simple design, and low cost [1,2]. Due to the unequal even- and odd-mode phase velocities, this filter suffers from the spurious responses at $2f_o$, equal to twice the passband frequency, which may seriously degrade the attenuation level in the stopband and passband response symmetry [3]. Various techniques have been proposed to tackle this problem [4-6]. The solutions are mainly obtained by providing different strip lengths to equalize phase velocities. In [4], an overcoupled resonator is proposed to compensate the difference in phase velocities. The capacitively compensated structures as addressed in [5] and [6] are also effective in suppressing the spurious passband at $2 f_o$.

Hairpin bandpass filter (H-BPF) structure, has resemblances with the above parallel-coupled filter [7], and it is widely used and preferable because of its compact size. Like the parallel-coupled structure, this H-BPF also suffers from the spurious response at the 2nd harmonics of the operating frequency. But, there are only a few studies about this harmonics suppression [8-9].

Against this background, this work presents a simple harmonics suppression scheme for H-BPF. By the continuous sinusoidal modulation in the coupled section of the filter [10], it is possible to suppress H-BPF harmonics. As such, all well-defined equations can be adopted to provide a fast and simple calculation of the physical parameters. The only modification to the traditional filter is that the widths of the microstrip lines will be in a periodic pattern with a strip width modulation parameter M represented in percentage. The spurious passband can be suppressed by this modulation parameter whilst the basic filter response is the one obtained from the classical hairpin filter design.

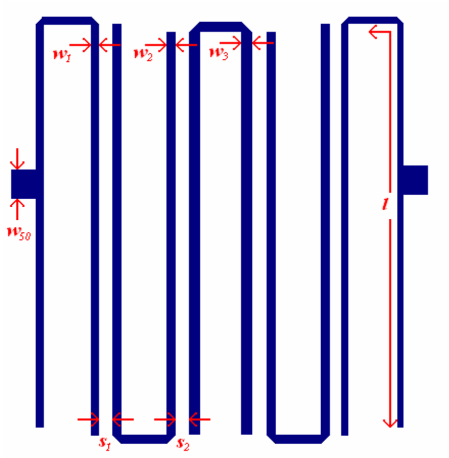
Besides this introductory section, the novel wiggly-line H- BPF will be presented in Section II with the emphasis on the strip modulation. In Section III, simulation and experimental results of the proposed filters are presented and compared with that of the conventional filter. Finally, a conclusion is drawn in Section IV.

II. NOVEL "WIGGLY-LINE" HAIRPIN FILTER

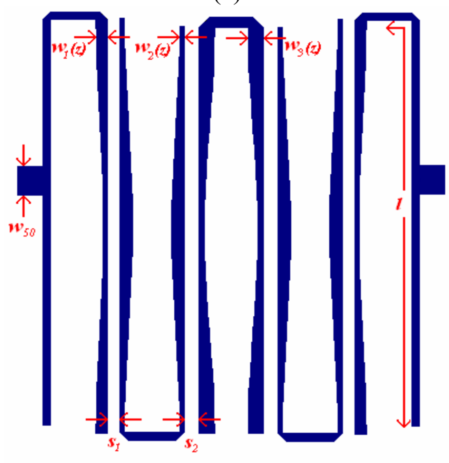
Fig. 1(a) shows the conventional hairpin filter and its design equations follow the parallel-coupled, half-wavelength resonator filters. In order to equalize the even and odd mode velocities, their impedances can be significantly controlled by the sinusoidal strip modulation as indicated in Fig. 1(b). Perturbation in strip-width controlled by a modulation parameter M is used to reject the unwanted harmonic passband. This perturbation will be introduced in an asymmetrical way, modulating the outer edge of the coupled lines, but keeping the inner edge unaltered. As such, the conductor strip-width variation $w_i(z)$ in the i^{th} coupled line section can be expressed as in (1), where z varies along the coupled-line section l_i, and the initial phase ϕ is fixed alternatively to 0^o and 180^o .

$$w_i(z) = w_i\left(1 + \frac{1}{2}\frac{M(\%)}{100}\cos\left(\frac{2\pi \cdot z}{l_i} + \phi\right)\right) \quad (1)$$

where ϕ is coupled-line pairs initial phase (0° and 180°), w_i and l_i are the constant widths and lengths calculated for the conventional filter, and M is the strip-width modulation parameter expressed in percentage. The optimal initial phase of the perturbation in every coupled-line section has been chosen to maximize the rejection level achieved in the undesired passbands.



(a)



(b)

Fig. 1. (a) Conventional hairpin bandpass filter, (b) hairpin wiggly-line bandpass filter.

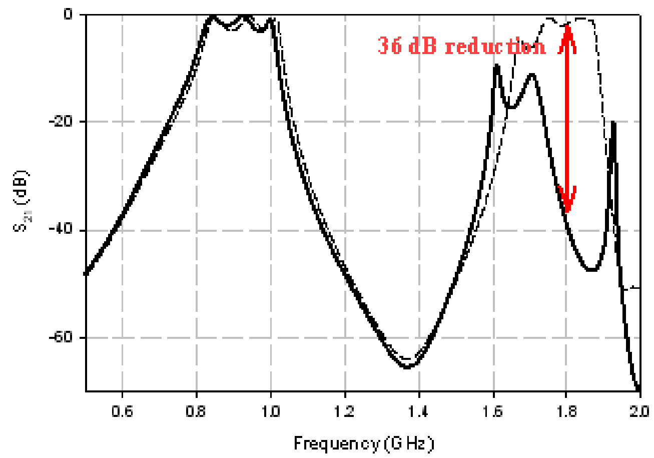
III. Simulations and Measurements

In order to demonstrate the spurious passband suppression capability of proposed filter structure, especially for the 2nd harmonic, two microstrip hairpin filters; including a conventional H-BPF and a novel wiggly-line H-BPF; are designed and simulated in MoM based EM simulation package [11]. A classical Butterworth bandpass filter centered @ 900MHz with 10% fractional BW is designed as the basic filter specifications. The microstrip filter is implemented on the substrate with relative dielectric constant $\varepsilon_r = 3.38$ and thickness h = 1.52 mm. Subject to the above specification, these two filters' layout parameters are evaluated and listed in Table 1. In this table, i is the section number, w_i is the strip width of the i^{th} section, s_i is the separation between the coupled lines of the i^{th} section and, l_i is the length of the i^{th} section. Based on this basic configuration, the novel wiggly-line H-BPF can be designed with M = 80% and a zero phase shift.

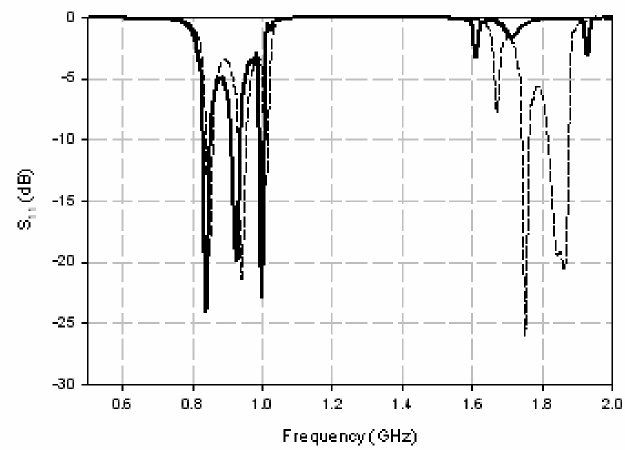
Fig. 2 shows the S-parameters simulation of these two filters. From Fig. 2(a), the proposed wiggly-line filter has reduced the 2nd harmonics to a value as low as -38dB. The proposed filter keeps a good matching as that of the conventional one, as illustrated in Fig. 2(b). Meanwhile, the $|S_{11}|$ at the 2nd harmonics also deteriorates 20dB.

i	w_i, mm	s_i, mm	l_i, mm	ε_{eff}
1	0.86	0.39	54	3.43
2	0.99	0.77	54	
3	1.20	---	54	

Table-1. Layout parameters for the conventional hairpin and wiggly-line H-BPF.



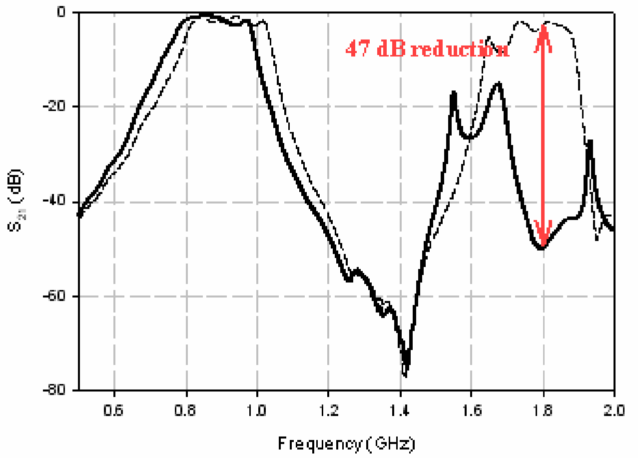
(a)



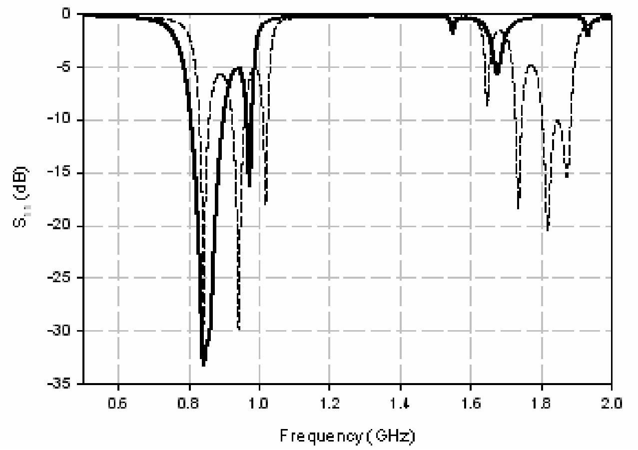
(b)

Fig. 2. (a) Simulated $|S_{21}|$ and (b) $|S_{11}|$ parameters for a conventional hairpin Butterworth bandpass microstrip filter centered at 900 MHz with a 10% fractional bandwidth (dashed line) and a "wiggly-line" H-BPF with M=80% (thick solid line).

In order to verify the simulation results, the above filters have been fabricated and the experimental behavior is shown in Fig 3. It can be observed that the experimental results match those of the simulations. There is around 47dB suppression of the 2nd harmonics. From Fig. 3(a), the stopband centered around $2f_o$ can be reduced to a level of ~-20dB. This indeed reports about 15dB spurious passband reduction. The measured passband matching is kept as good as 32dB as shown in Fig 3(b).



(a)



(b)

Fig. 3. (a) Measured |S21| and (b) |S11| parameters for a conventional hairpin Butterworth bandpass microstrip filter centered at 900 MHz with a 10% fractional bandwidth (dashed line), for a “wiggly-line” filter with M=80% (thick solid line).

In addition, the measured proposed filter passband suffers 0.8dB loss, as depicted in Fig. 4. Moreover, the proposed filter deviates about 50MHz, which is mainly due to the substrate loss that was not considered in the simulation. The above results confirm indeed the performance of this new filter structure. Fig. 5 presents the photograph of the prototype microstrip filters having the dimension 46x56 mm^2, respectively.

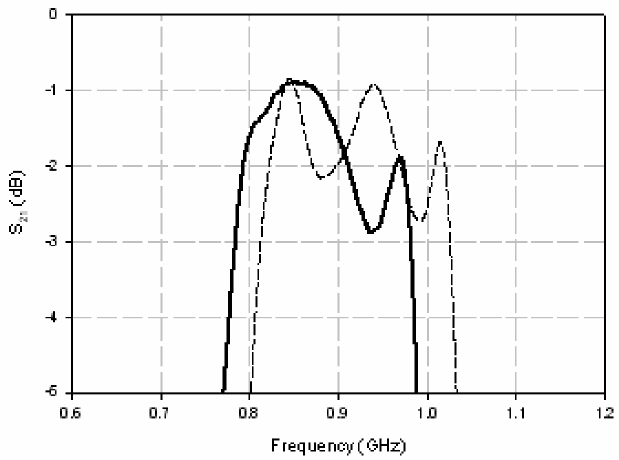
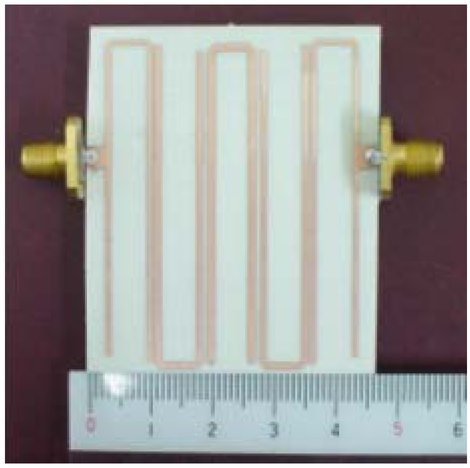
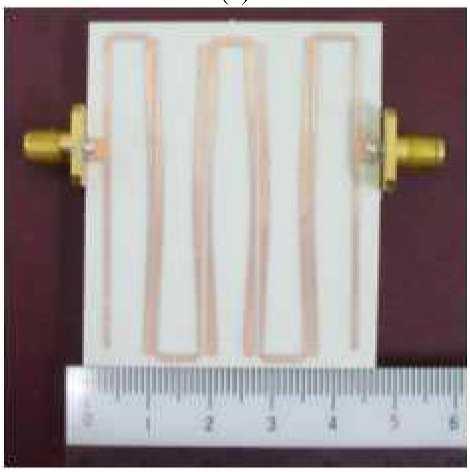


Fig. 4. The comparison of passband responses between the conventional (dashed line) and the wiggly-line filter (thick solid line).



(a)



(b)

Fig. 5. Photograph of the prototype filters: (a) conventional H-BPF and (b) wiggly-line H-BPF.

IV. Conclusion

A novel wiggly-line filter based on the strip-width modulation reformulation is proposed to suppress the spurious passband at the second harmonics of the operating frequency. This wiggly-coupled line H-BPF equates the odd-mode and even-mode phase velocities such that the second spurious harmonics can be suppressed. In order to verify the practical performance of this novel filter structure, two prototype microstrip filters @900MHz are designed and experimentally characterized. It is reported that more than 47dB 2nd harmonic reduction can be obtained with the proposed filter. This new method offers additional design flexibility for the conventional hairpin filter design.

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