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A NOVEL AND COMPACT UWB BANDPASS FILTER USING MICROSTRIP FORK-FORM RESONATORS

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Abstract—A novel and compact ultra wideband (UWB) bandpass filter (BPF) with two transmission zeros near both passband edges of lower and higher frequency is proposed by using a new structure of fork-form resonators. The fork-form resonator generates a attenuation pole at the higher passband edge, lower insertion loss, wider bandwidth and compacter dimension, as compared with the traditional parallel unilateral-coupled resonator. A microstrip bandpass filter cascaded by two stages fork-form resonators with a 3-dB fractional bandwidth of 128% (from 1.0 GHz to 4.6 GHz) is designed, fabricated, and tested. The measured characteristics of the filter agree with the theoretical simulations, and the measured results show good specifications which are very low insertion loss 0.5 ± 0.3 dB within the passband and good return loss less than -15 dB from 1.5 GHz to 4.0 GHz, respectively.

1. INTRODUCTION

Ultra wideband radar and high data-rate communication systems require RF/Microwave circuits capable of operating over wide frequency ranges [1–4]. In the recent years, RF/Microwave passive devices of wideband were extensively investigated and a number of compact filters exhibiting very wide passbands had been proposed using different techniques, such as microstrip and uniplanar circuits [5–8]. The parallel coupled microstrip bandpass filters using $\lambda_g/2$ [9] or $\lambda_g/4$ [10, 11] resonators are widely used to the modern communication and radar systems. Generally, the parallel coupled resonator unit using $\lambda_g/4$ is an unilateral-coupled operational mode, as shown in Figure 1. However, the traditional parallel coupled BPF usually obtains very high insertion loss, which is disadvantageous to the structure of BPF. In order to reduce the insertion loss of filter, the separation of coupled lines can be decreased to some extent, while this method makes conversely it difficult to manufacture the printed circuit board of the filter.

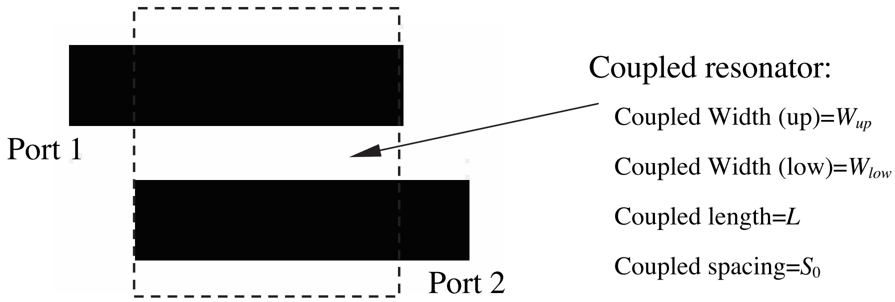

Figure 1. A conventional parallel unilateral-coupled resonator.

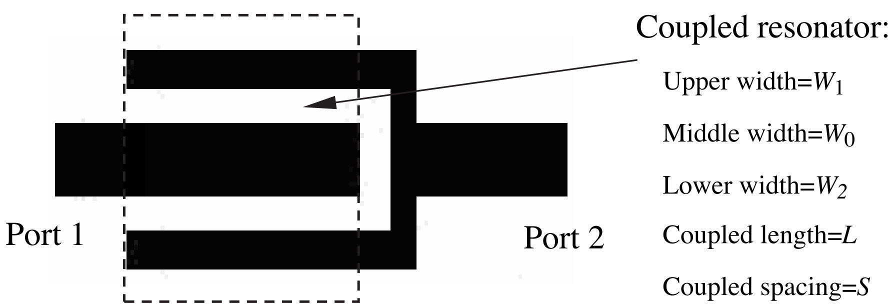

Figure 2. A modified parallel bilateral-coupled resonator.

In this paper, a novel and compact low insertion loss UWB BPF with good rejection performance is developed by using microstrip fork-form resonators, as shown in Figure 2. First, theoretical analysis of the proposed fork-form resonator is carried out from the point of view of odd- and even-model. Then a bandpass filter cascaded with two microstrip fork-form resonators is designed, fabricated, which owns a 3-dB fractional bandwidth of 128% (from 1.0 GHz to 4.6 GHz). The measured frequency response of the filter agrees with the theoretical simulations. The measured insertion loss 0.5 ± 0.3 dB within the passband, and return loss less than -15 dB from 1.5 GHz to 4.0 GHz, respectively. Moreover, a transmission zero is produced in the upper side of the passband edge, which leads to a good rejection in the higher stopband.

2. ANALYSIS AND DESIGN OF THE UWB BPF

2.1. Analysis of the Bandpass Filter

Figure 1 shows a conventional microstrip resonator using parallel unilateral-coupled transmission line. Because of its symmetrical property, the structure can be analyzed by adopting odd- and even-mode technique [11–15]. According to reference [16], we can obtain the following Equation (1) to design the unilateral-coupled bandpass filter.

$$Z_{in} = \frac{1}{2\sin(\beta l)}\sqrt{(Z_{0e} - Z_{0o})^2 - (Z_{0e} + Z_{0o})^2 \cos^2(\beta l)} \tag{1}$$

where,

Z_{0e}: the characteristic impedance for the even modes,

Z_{0o}: the characteristic impedance for the odd modes,

β: the propagation constant in the lossless transmission line.

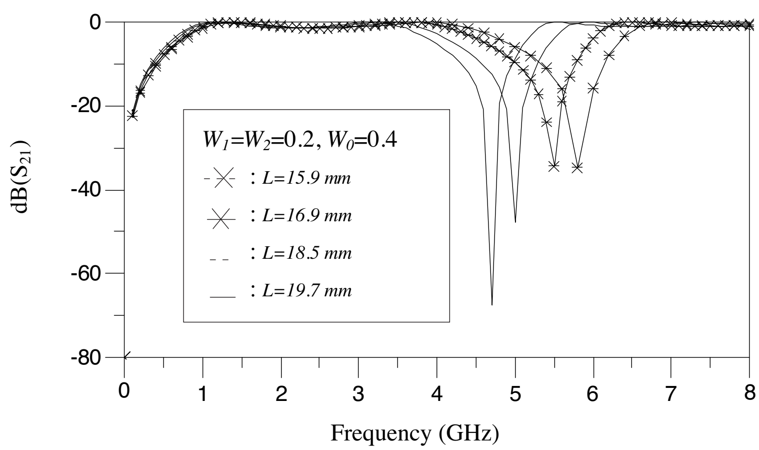

Figure 3. The transmission characteristics of different resonator lengths.

A modified parallel bilateral-coupled resonator is shown in Figure 2. The widths of external coupled lines are identical, i.e., W_1 (upper width) = W_2 (lower width), and the width of the middle transmission line is W_0. According to references [17–20], we can analyze and design the modified resonator. Figure 3 shows the transmission repose of the modified bilateral-coupled resonator with different coupled lengths. From the simulated results, when the length of spacing between coupled lines L is equal to 19.7 mm, the transmission zero near the higher passband side is about -65 dB at 4.7 GHz, and the insertion loss is about 0.7 ± 0.4 dB from 1 GHz to 3.6 GHz.

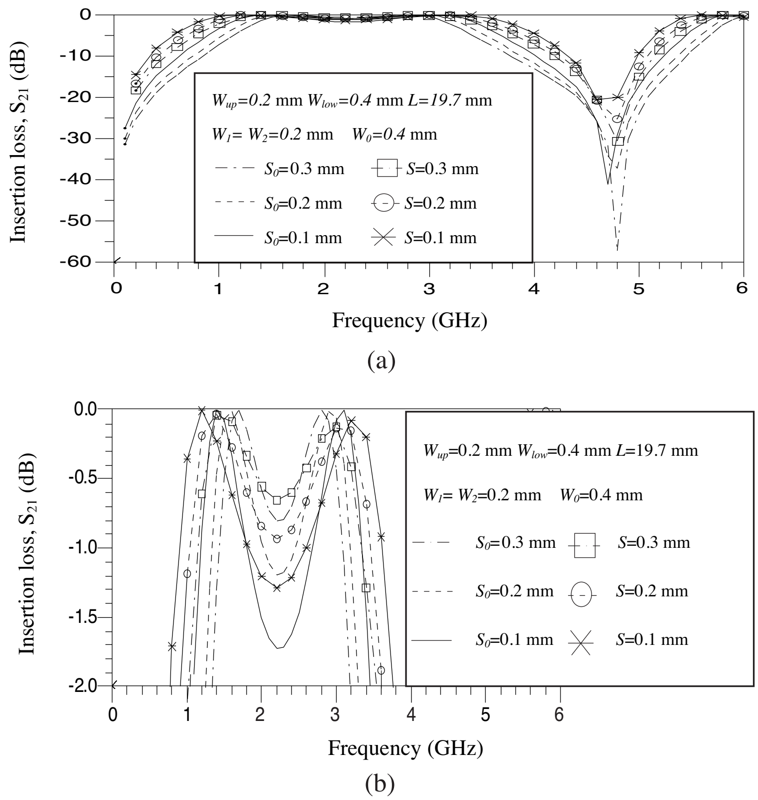

Figure 4. (a) Simulated frequency response of the coupled-line section (two-coupled line or three-coupled line) as function of spacing (S or S_0). (b) Locally amplified frequency response of Figure 4(a).

Figure 4 shows the transmission characteristics which are compared unilateral coupled resonator with bilateral coupled one, when the parameters of both resonators are fixed at $W_{up} = 0.2$ mm, $W_{low} = 0.4$ mm, $L = 19.7$ mm, $W_1 = W_2 = 0.2$ mm, $W_0 = 0.4$ mm, respectively. From the Figure 4(a) and 4(b), the bilateral-coupled resonator obtains wider bandwidth and lower insertion loss than the unilateral-coupled one. In addition, the response feature of the bilateral-coupled resonator is improved as the separation S between the coupled lines decreases. Therefore, we choose the spacing $S = 0.1\,\mathrm{mm}$ during the design of UWB BPF.

2.2. Synthetic Design of the Bandpass Filter

According to analyze above Section 2.1, we can divide the topology of circuit into two parts during the design process of UWB BPF, as discussed in the previous analysis. Firstly, parameters determining the electrical performance of the filter structure were analyzed using both circuit and full-wave electromagnetic simulations. Then, we can design synthetically and optimize the filter, and obtain the requirement results. From the above simulated results, the insertion loss of the filter can be further decreased, and the bandwidth of the filter can be further increased, if we use two-stage cascaded fork-form resonators. In order to improve the return loss of the ultra wideband BPF, we design $\lambda_g/4$ impedance transformers with length len_1 and len_2 at the both ends of the filter, respectively. The principled block diagram of the microstrip fork-form BPF is shown in Figure 5. The final configuration and key dimensions of the proposed UWB BPF are shown in Figure 6. Finally, a low-cost FR4 PCB with the dielectric constant of 4.4 and 2.4-mm-thick is used to fabricate the filter.

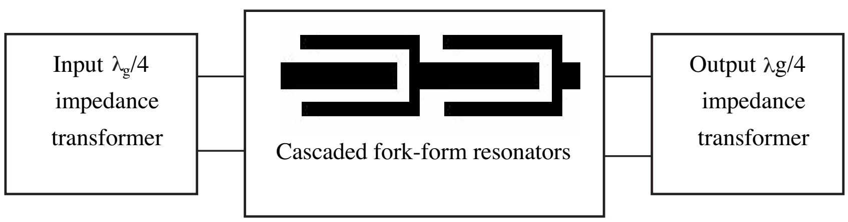

Figure 5. The circuit topology of the proposed UWB BPF.

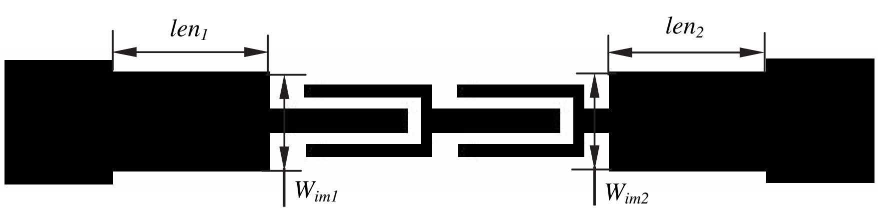

Figure 6. The geometry dimensions of the proposed UWB BPF.

The initial values of these main parameters which we can obtain them by the technique introduced above Section 2.1 are shown as following: $len_1 = len_2 = 14.0\,\mathrm{mm}$, $W_{im1} = W_{im2} = 2.8\,\mathrm{mm}$, $W_1 =$

$W_2 = 0.2\,\text{mm}$, $W_0 = 0.4\,\text{mm}$, $L = 19.7\,\text{mm}$, $S = 0.1\,\text{mm}$. In order to implement the specifications of the bandpass filter, we have to optimize these initial parameters with the electromagnetic (EM) simulator. As a result, the overall dimension of the printed circuit board is about $10.0\,\text{mm} \times 70.0\,\text{mm}$.

3. RESULTS AND DISCUSSION

According to the above analysis and design process, we simulate firstly the ultra wideband bandpass filter with RF/Microwave circuit simulator. Then, with the EM simulator, we optimize the electrical parameters of the filter. The simulated and measured results shown in Figure 7 agree with each other. From the measured results, the center frequency f_0 of 2.8 GHz, the insertion loss of the filter is about $0.5 \pm 0.3\,\text{dB}$, the ultra wide bandwidth of 1.0 GHz $\sim$ 4.6 GHz with 3-dB fractional bandwidth of 128%, and widely matched return loss less than $-15\,\text{dB}$ from 1.5 GHz to 4.0 GHz, respectively. The bandwidth of the filter can be controlled and adjusted by the spacing S between the coupled lines. Moreover, the attenuation poles is clearly observed in the higher passband edge near 5.6 GHz with $-35\,\text{dB}$ attenuation. The measured results have verified the proposed UWB BPF design concept.

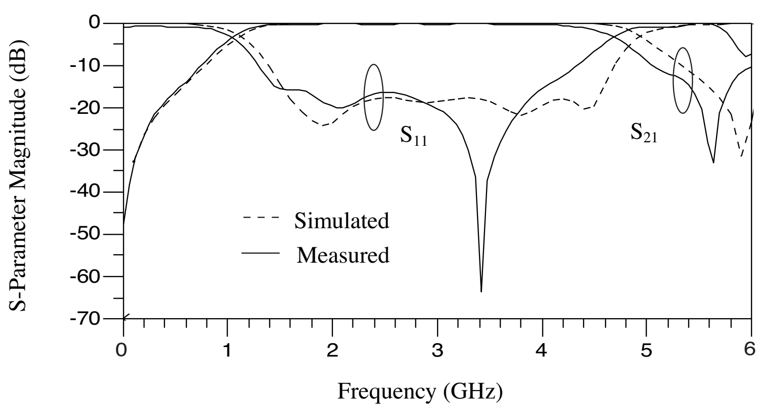

Figure 7. Frequency response of the UWB BPF.

By the way, although the measured results are slightly different with the simulated ones in the higher band, which can be considered as the man-made fabricated error and the SMA connector effect on the measurement, the proposed UWB BPF still shows a good potential for broadband communication, and realization on the commercial PCB substrate without using expensive lithography process.

4. CONCLUSION

In this paper, we analysis and design the ultra wideband bandpass filter using microstrip cascaded fork-form resonators. Different with the traditional parallel unilateral-coupled resonator, the parallel bilateral-coupled unit is used to construct the fork-form resonant component. Therefore, the electrical performance of the filter is improved greatly, including the insertion loss reduction and the attenuation pole near the higher side of passband edge clearly observed, and the width of passband also increase. The measured characteristics of the filter agree with the theoretical simulations, and the measured results show good specifications which are very low insert loss 0.5 ± 0.3 dB within the passband and good return loss less than -15 dB from 1.5 GHz to 4.0 GHz, respectively. Therefore, the overall design results can achieve completely the engineering requirements.

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