Novel Reduced-Size Coplanar-Waveguide Bandpass Filter Using the New Folded Open Stub Structure

Shry-Sann Liao, *Member, IEEE*, Hsien-Ku Chen, Yin-Cheng Chang, and Kun-Tai Li

***Abstract*—This letter proposes a novel folded skill and a simpler method than that of older methods. The advantages of this new structure reveals a better skirt factor than that of the conventional folded $\lambda/4$ series open stub, and it reduces the folded area of the conventional structure by at least 50%. Besides, by using the new folded $\lambda/4$ open stub to realize a bandpass filter, the size of the circuit will be reduced greatly and achieve better stopband rejection.**

***Index Terms*—Coplanar-waveguide (CPW) structures, folded $\lambda/4$ open stub, reduced-size bandpass filter.**

I. Introduction

THE ADVANTAGES of the coplanar waveguide (CPW) structures in the design of microwave and millimeter wave circuits are ease in series and shunt connections, no via hole, insensitive to the substrate thickness, and low dispersion effect. Up until now, several CPW filters have been reported in literature [1]–[3]. An end-coupled CPW filter was proposed by cutting gaps in the center [1], but the gap capacitance is usually not large enough to satisfy with designing. Also, the method of coupled is inductively-coupled utilized to realize a shunt inductively-coupled CPW filter, and has the characteristics of low insertion loss and good stopband rejection [2]. Lin and his colleagues suggested that one can connect many $\lambda/4$ open series stubs to design broad-band bandpass filters[3]. All of the above authors are based on the fixed wavelength resonator to design the filters. If we want to get more stopband rejection, we should increase its orders so we can predict that the filter would occupy more circuit dimension.

Recently, there have been some methods proposed to reduce the size of the filter [4]–[6]. In [4], they use photonic bandgap structure (PBG) to improve the stopband rejection, and the structure produces the slow-wave to reduce the size of the filter. If we consider the skills of the bended and folded to reduce the size of the filter and to get the better stopband rejection [5], it still occupies too large an area of the folded. Furthermore, Weller [6] suggested a folded $\lambda/4$ open series stub structure to achieve the goal of size-reduction. However, its folded area is still too large, and the transition band is not sharp enough. Therefore, we concentrate on how to establish two new folded skills, type1 and type2, in Section II of this letter. Then, we applied one of them, type2, to design a reduced-size bandpass filter, as shown in Fig. 1. The detailed descriptions of this circuit are submitted in Section III of this letter. The advantage of the type2 reveals the better skirt factors than that of the conventional folded $\lambda/4$ series open stub, and reduces the folded area of the conventional structure by at least 50%. Moreover, this novel folded skill expresses a simpler method than that of the previous method. However, we applied this new folded structure to design the reduced-size bandpass filters. The measured and simulated results are compared and good agreement between them is observed.

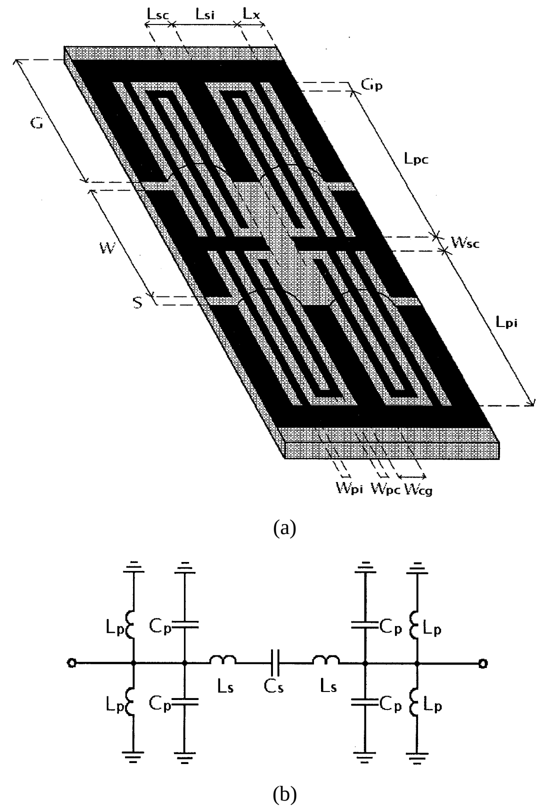

Fig. 1. Reduced-size CPW bandpass filter: (a) Configuration ($G = W = 7$ mm, $Lsc = Lx = 1.5$ mm, $Lsi = 3.5$ mm, $Lpc = 9.5$ mm, $Lpi = 10$ mm, $S = Wpi = Wpc = Gp = 0.5$ mm, $Wsc = 1$ mm). (b) Equivalent circuit ($Lp = 0.75$ nH, $Cp = 5.7$ pF, $Cs = 0.35$ pF, $Ls = 6$ nH).

II. New Folded $\lambda/4$ Open Stub

In general, a simple CPW $\lambda/4$ series open stub, as shown in Fig. 2, has the bandpass response [6], but the bad selectivity exists, and the transition band is not sharp enough. In order to improve these situations, we consider the folded skill on $\lambda/4$ series open stub circuit. Generally speaking, the way of this method is to fold both sides toward the center, and to simultaneously fold the center conductor toward both sides, as shown in Fig. 3(a) [6]. This structure was obviously too complicated and occupied too

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The authors are with the RF Circuits Design Laboratory, Department of Communication Engineering, Feng Chia University, Taichung, Taiwan, R.O.C.

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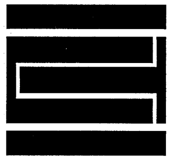

Fig. 2. Nonfolded $\lambda/4$ series open stub.

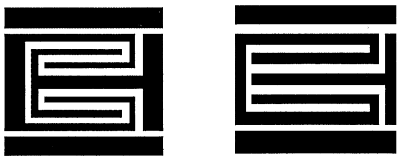

Fig. 3. Two kinds of the folded $\lambda/4$ open stub: (a) Conventional fold [6]. (b) New folded type1.

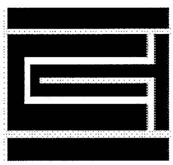

Fig. 4. New folded type2.

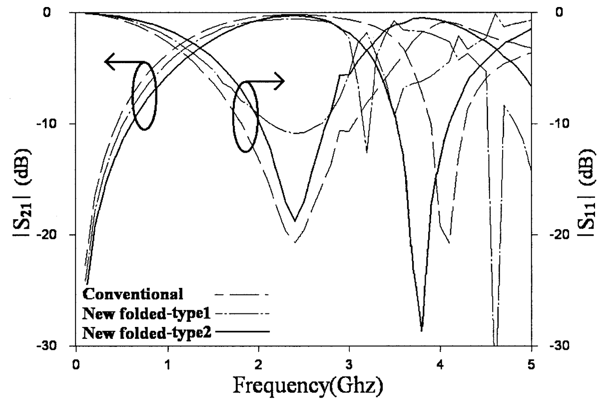

Fig. 5. Simulated response for the three-folded $\lambda/4$ open stub.

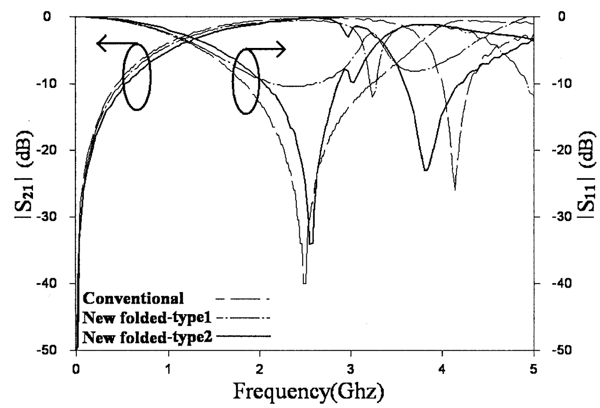

Fig. 6. Measured response for the three-folded $\lambda/4$ open stub.

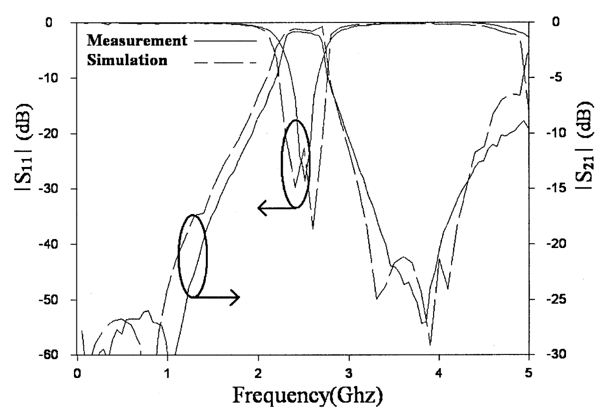

Fig. 7. Simulated and measured response of the reduced-size CPW bandpass filter.

many dimensions. Therefore, we try to fold both sides toward the center conductor only, and to keep the center conductor nonfolded, as shown in Fig. 3(b). The simulated results are shown in Fig. 5. This new structure of the folded stub is improved continuously to get a better shape factor. We suggest a novel folded skill, as shown in Fig. 4, and a simpler method than that of the previous methods which are shown in Figs. 2 and 3.

First, we keep the sides of the $\lambda/4$ series open stub the same as that of the nonfolded. Second, we fold the stub in the middle of conductor only. Certainly, the new structure is still based on the $\lambda/4$ series open stub, but our structure folds the $\lambda/4$ open stub directly to make the folding simple. From the point of view of the junction, the new folded skill makes for less series capacitance, which gives us a better skirt factor. We simulate the conventional and new folded $\lambda/4$ series open stub by the full-wave Sonnet em simulator, and the results of the simulation are shown in Fig. 5. All implemented circuits in this letter are fabricated on the FR4 substrate ($\varepsilon_r = 4.7$, $\tan\delta = 0.022$, thickness $=$ 0.8 mm) and the metal thickness $= 0.02$ mm. The results of measurements are shown in Fig. 6. From those data, we get the advantage of this new structure, revealing a better skirt factor than the conventional folded $\lambda/4$ series open stub, and reducing the folded area of the conventional structure by at least 50%. Certainly, we can also increase the repeated times of the folding to make the skirt factor better than that of the single folded by decreasing the effective length of the open stub.

III. Application to Reduced-Size Bandpass Filter

This new folded structure is applied on the circuit to design a reduced-size bandpass filter, as shown in Fig. 1(a), and is proposed and examined, which has an equivalent circuit, shown in Fig. 1(b). In the circuit, we consider that the bended $\lambda/4$ short stub is equivalent to a shunt inductance, the bended $\lambda/4$ open stub is equivalent to a shunt capacitor, and we apply the fundamental circuits of the bandpass filter to get its structure. If we want to improve the cutoff rate of the filter, we enlarge Lsc or shorten Lsi. If we want to improve effect of the nearby multi-harmonics, we decrease Wsc and increase Lpc under the condition of $2Lpc + Wsc =$ constant, but it will cause the effect of the center frequency shift to the side of the low frequency. However, the simulated and measured results are shown in Fig. 7. Also, the measurement and simulation results are compared, and in good agreement between them is observed. This bandpass filter reveals a good shape factor, and the reduced factor could reach 66%. (original circuit reduced from 29.5 mm $\times$ 28 mm to 11.5 mm $\times$ 24 mm).

IV. Conclusion

In this letter, we have proposed a novel folded skill, type2, and a simpler method than that of older methods. The advantages of this new structure are that it reveals a better skirt factor than that of the conventional folded $\lambda/4$ series open stub, and it reduces the folded area of the conventional structure by at least 50%. We can also increase the repeated times of the folding to make the skirt factor better than that of the single folded. Then, we applied this new structure to design a reduced-size bandpass filter. This bandpass filter reveals a good shape factor, and the reduced factor could reach 66%. Moreover, we can adjust Lsc, Lsi, Lpc, and Wsc to improve its cutoff rate and the effect of the nearby multiharmonics.

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