Novel Reduced-Size Coplanar-Waveguide Bandpass Filters

Yu-Kang Kuo, Chi-Hsueh Wang, and Chun Hsiung Chen

***Abstract*—Two novel reduced-size coplanar-waveguide (CPW) bandpass filters are proposed. Specifically, the bended short-end parallel stubs together with the folded open-end series stubs are utilized to design a broadband filter, and the slow-wave structures are adopted to implement a narrowband filter. In this study, the proposed filters are examined, theoretically and experimentally.**

***Index Terms*—Coplanar-waveguide structure, reduced-size bandpass filter.**

I. INTRODUCTION

BANDPASS filters with small size and light weight are fundamental components of communication systems. In the past, most of the filters are realized based on the microstrip-line technology. Recently, coplanar waveguide (CPW) structure has gained popularity in the design of microwave and millimeter wave circuits due to the merits such as ease in series and shunt connections, no via hole, insensitive to the substrate thickness, and low dispersion effect. Up to now, several CPW filters have been reported in the literature [1]–[5]. Williams [1] proposed an end-coupled CPW filter by cutting gaps in the center conductor of CPW so as to create the capacitively-coupled resonant sections. However, the gap capacitance is usually not large enough to meet the design requirements, especially in the implementation of wideband bandpass filters. In addition to the capacitively (gap)-coupled filter, the dual form of using the CPW shunt inductors as the impedance inverters to realize a shunt inductively-coupled CPW bandpass filter was presented in [2]. The filters in [1], [2] occupy large circuit area due to the use of half-wavelength ($\lambda/2$) resonators. Nguyen [3] proposed the broadside end-coupled CPW bandpass filter to achieve wide-bandwidth characteristics but the uniplanar feature of CPW would be destroyed. The ribbon-of-brick-wall type CPW bandpass filter was built by cascading several sections of quarter-wavelength ($\lambda/4$) open-end series stubs [4]. The broadband CPW bandpass filter consisting of $\lambda/4$ open series stubs and $\lambda/4$ short parallel stubs was proposed in [5]. Alternatively, an LC-coupled CPW bandpass filter with $\lambda/4$ resonators was examined by [6]. At low frequencies, however, these filters still occupy considerable amount of areas due to the use of several $\lambda/4$ sections.

Recently, Lin and Chen [7] proposed a reduced-size CPW-to-slotline transition that uses a twin-spiral slotline structure to replace the conventional $\lambda/4$ slotline. Weller [8] also proposed a folded series stub structure to achieve the goal of size-reduction. In this study, a new reduced-size broadband CPW bandpass filter is proposed, using the bended short-end parallel CPW stubs together with the folded open-end series CPW stubs to replace the conventional parallel and series $\lambda/4$ stubs. This reduced-size broadband CPW bandpass filter has the merits of compact size, high cutoff rate, and low insertion loss in passband. In this study, a reduced-size narrowband CPW bandpass

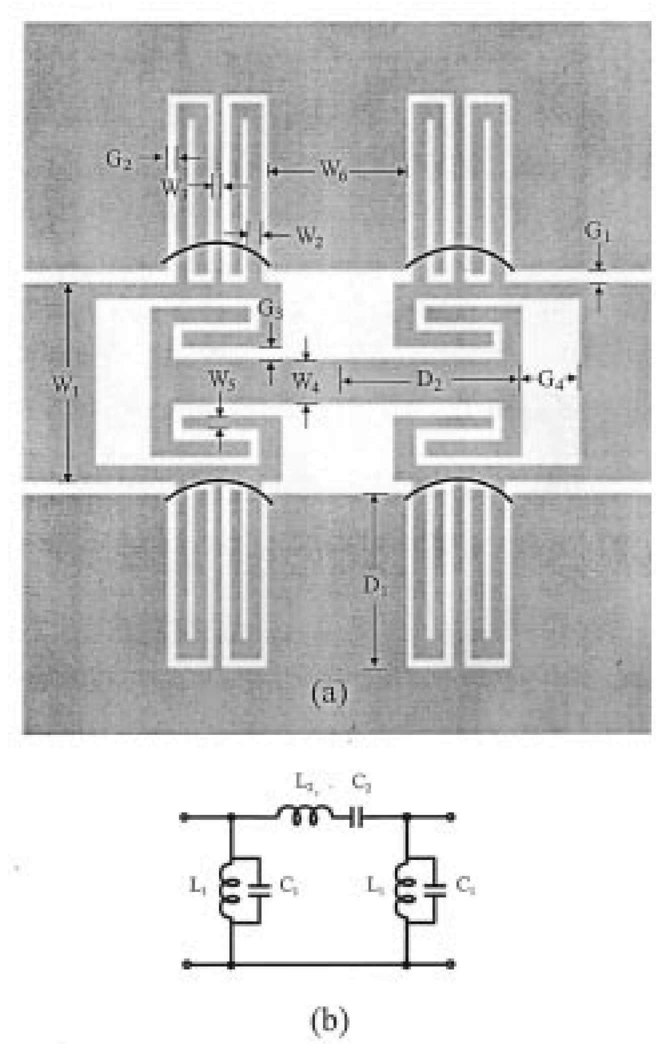

Fig. 1. Reduced-size broadband CPW bandpass filter: (a) configuration ($G_1 = 0.6$ mm, $G_2 = 0.5$ mm, $G_3 = 0.4$ mm, $G_4 = 3$ mm, $W_1 = 7$ mm, $W_2 = W_3 = 0.5$ mm, $W_4 = 1.6$ mm, $W_5 = 0.4$ mm, $W_6 = 7$ mm, $D_1 = 6.4$ mm, $D_2 = 9.5$ mm); (b) equivalent circuit ($L_1 = 2.637$ nH, $L_2 = 6.44$ nH, $C_1 = 16.7$ pF, $C_2 = 6.84$ pF).

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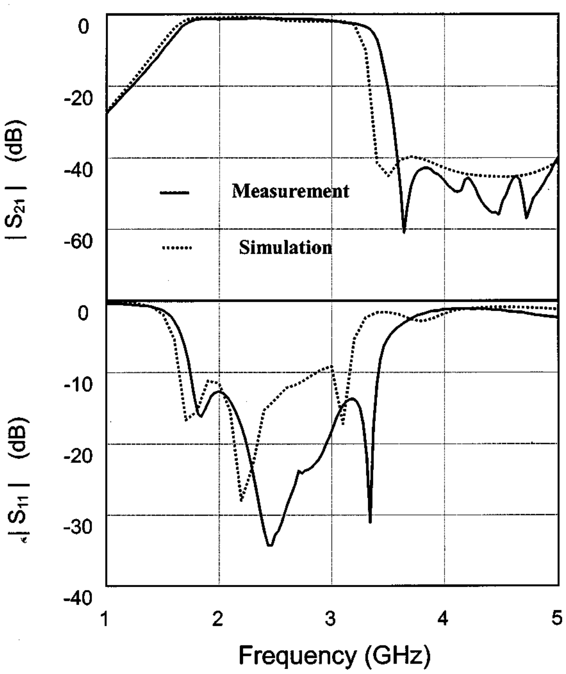

Fig. 2. Measured and simulated results for reduced-size broadband CPW bandpass filter (Fig. 1).

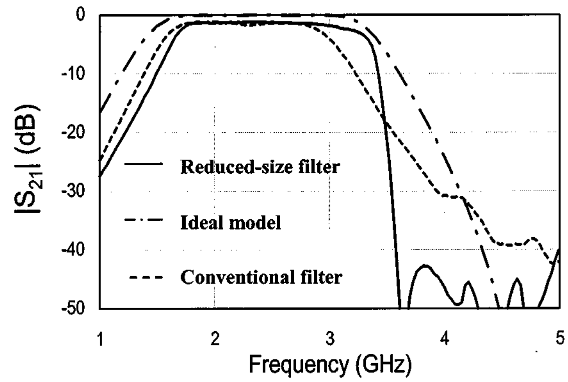

Fig. 3. Measured results for reduced-size filter (Fig. 1) and conventional $\lambda/4$ filter [5]. Also included is the result based on ideal transmission-line model.

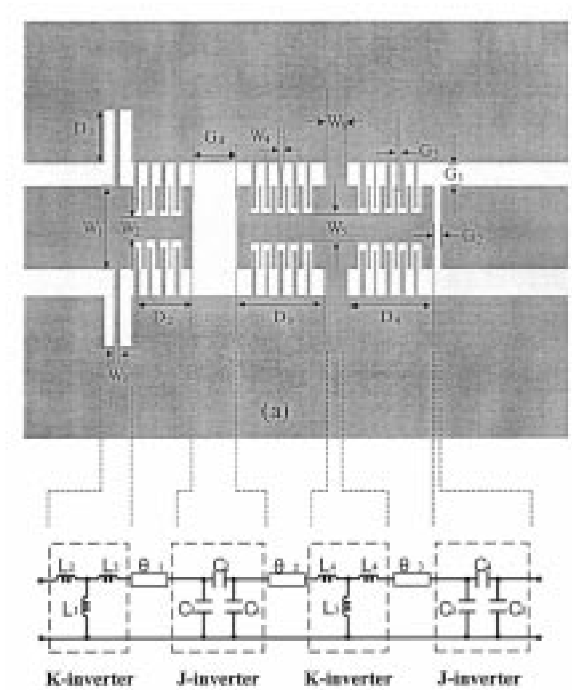

Fig. 4. Reduced-size narrowband CPW bandpass filter: (a) configuration ($G_1 = 1$ mm, $G_2 = 0.7$ mm, $G_3 = 0.3$ mm, $G_4 = 3.3$ mm, $W_1 = 3$ mm, $W_2 = 0.8$ mm, $W_3 = 0.5$ mm, $W_4 = 0.3$ mm, $W_5 = 1$ mm, $W_6 = 2.2$ mm, $D_1 = 2$ mm, $D_2 = 5.45$ mm, $D_3 = 8.05$ mm, $D_4 = 7.8$ mm); (b) equivalent circuit ($L_1 = 0.537$ nH, $L_2 = 0.1$ nH, $L_3 = 0.05$ nH, $L_4 = 0.01$ nH, $C_1 = 0.028$ pF, $C_2 = 0.10$ pF, $C_3 = 0.03$ pF, $C_4 = 0.26$ pF, $\lambda c_1 = 117.9°$X, $\lambda c_2 = 100.4°$X, $\lambda c_3 = 101.8°$X).

filter is also proposed, using the slow-wave structures [9] to replace the $\lambda/4$ resonators in an LC-coupled CPW bandpass filter [6]. These proposed filters are designed, simulated, and fabricated. The measured and simulated results are compared and good agreement between them is observed.

II. Reduced-Size Broadband Bandpass Filter

In this study, a novel reduced-size broadband CPW bandpass filter structure, shown in Fig. 1(a), is proposed and examined, which has an equivalent circuit, shown in Fig. 1(b). Here, the L_1C_1 and L_2C_2 circuits may be realized by the $\lambda/4$ short-end parallel stubs and $\lambda/4$ open-end series stubs, respectively, as in the conventional $\lambda/4$ bandpass filter [5]. To reduce the size of the proposed filter, the bended short-end parallel stubs and the folded open-end series stubs are utilized to replace the conventional $\lambda/4$ short-end parallel and open-end series stubs. Note that the bended or folded stub structure has the total length around $\lambda/4$.

Basically, the performances of bended and nonbended short-end stubs are similar except that the bandwidth is reduced and the upper cutoff is sharper in the bended structure. The bended stub results in sharper cutoff and narrow bandwidth due to the associated parasitic capacitive and inductive effects, which also slightly change the total length of bended stub structure when compared with the nonbended $\lambda/4$ stub. But the bended stub structure can reduce the size up to one third of the nonbended one.

To reduce the size of the series open-end CPW stub in [5], the folded open stub structure proposed by [8] is used to implement the reduced-size filter as shown in Fig. 1(a). The performances of both folded and nonfolded open stub structures are similar, but the size of the folded one may be reduced to half of the nonfolded one.

Both reduced-size filter (Fig. 1) and conventional $\lambda/4$ filter [5] are fabricated on the FR4 substrate ($\varepsilon_r = 4.5$, $\tan\delta = 0.022$, thickness $h = 1.6$ mm) and are then simulated by the IE3D software. Shown in Fig. 2 are the measured and simulated results for the new filter structure (Fig. 1). The center frequency of this filter is 2.4 GHz and the 3 dB-bandwidth is 50%. The new filter is designed to have a Chebyshev response with 0.01 dB ripple. The feed and output CPW lines have the same characteristic impedances of $Z_0 = 50\ \Omega$. Good agreement between the measured and simulated results is observed. In the passband,

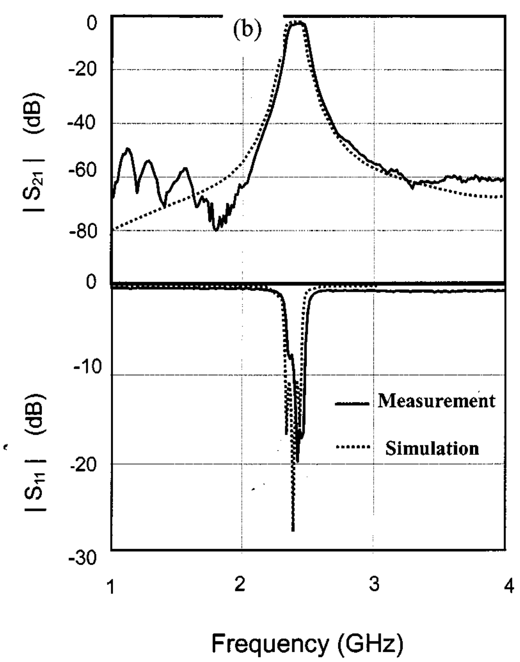

Fig. 5. Measured and simulated results for reduced-size narrowband CPW bandpass filter Fig. 4.

the return loss is lower than −13 dB with the insertion loss not exceeding −1.4 dB.

In Fig. 3, the measured result of reduced-size filter (Fig. 1) is compared with that of the conventional $\lambda/4$ filter [5]. Also included in Fig. 3 is the simulated result for the $\lambda/4$ filter using the ideal transmission-line model. The cutoff rate of the reduced-size filter is found to be the sharpest one, especially in the high frequency band, due to the use of bended short-end stub. The passband characteristics of these filter structures are similar. But the area of the new filter (Fig. 1) (21 mm $*$ 25 mm) is only one quarter of the conventional $\lambda/4$ filter (40 mm $*$ 51 mm).

III. Reduced-Size Narrowband Bandpass Filter

In this study, a novel reduced-size narrowband CPW bandpass filter [Fig. 4(a)] is also examined. It is a modified version of the LC-coupled CPW filter, which is coupled alternatively by the K- and J-inverters [6]. The proposed filter has an equivalent circuit as shown in Fig. 4(b). By the use of LC-coupled structure with two different kinds of inverters, the filter may be realized by the $\lambda/4$ resonators [6]. To further reduce the filter size, the slow-wave structures [9] are utilized to replace the conventional $\lambda/4$ resonators. The total lengths of slow-wave structures are approximately of the order of $\lambda/4$. Shown in Fig. 5 are the measured and simulated results for the new filter structure (Fig. 4). This new filter is designed to have a third-order Chebyshev response with 0.3 dB ripple. The center frequency is 2.4 GHz and the 3 dB-bandwidth is 3 %. The feed and output CPW lines have the same characteristic impedances of $Z_0 = 50\ \Omega$. The filter is fabricated on the Duroid substrate ($\varepsilon_r = 10.2,\ \tan\delta = 0.0035$, thickness $h = 1.27$ mm). Good agreement between the measured and simulated results is again observed. The area of the proposed filter (Fig. 4) is 3/5 of the conventional LC-coupled CPW bandpass filter [6].

IV. Conclusion

Two reduced-size CPW bandpass filters, broadband and narrowband, have been proposed. The proposed broadband filter (Fig. 1) can effectively reduce the area with size-reduction factor up to 1/4 and its cutoff rate is sharper. The area of the new narrowband filter (Fig. 4) is 3/5 of the conventional LC-coupled CPW bandpass filter with $\lambda/4$ resonators. These reduced-size filters have good performance and are attractive in MIC/MMIC applications.

References

[1] D. F. Williams and S. E. Schwarz, “Design and performance of coplanar waveguide bandpass filters,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 558–566, July 1983.
[2] J. K. A. Everard and K. K. M. Cheng, “High performance direct coupled bandpass filters on coplanar waveguide,” *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 1568–1573, Sept. 1993.
[3] C. Nguyen, “Broadside-coupled coplanar waveguides and their end-coupled band-pass filter applications,” *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 2181–2189, Dec. 1992.
[4] F. L. Lin, C. W. Chiu, and R. B. Wu, “Coplanar waveguide bandpass filter—A ribbon-of-brick-wall design,” *IEEE Trans. Microwave Theory Tech.*, vol. 43, pp. 1589–1596, July 1995.
[5] K. Hettak, N. Dib, A. F. Sheta, and S. Toutain, “A class of novel uniplanar series resonators and their implementation in original applications,” *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 1270–1276, Sept. 1998.
[6] F. L. Lin, “Coplanar waveguide discontinuities full-wave analysis and filter design,” Ph.D. dissertation, Dept. Elect. Eng., Nat. Taiwan Univ., Taipei, Taiwan, R.O.C., May 1998.
[7] Y. S. Lin and C. H. Chen, “Design and modeling of twin-spiral coplanar-waveguide-to-slotline transitions,” *IEEE Trans. Microwave Theory Tech.*, vol. 48, pp. 463–466, Mar. 2000.
[8] T. M. Weller and L. P. Katehi, “Miniature stub and filter designs using the microshield transmission line,” in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1995, pp. 675–678.
[9] A. Gorur, C. Karpuz, and M. Alkan, “Characteristics of periodically loaded CPW structures,” *IEEE Microwave Guided Wave Lett.*, vol. 8, pp. 278–280, Aug. 1998.