Finite-Ground Coplanar-Waveguide Branch-Line Couplers

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***Abstract*—Two branch-line (BL) couplers based on finite-ground coplanar-waveguide (FGCPW) structures are proposed. The first one uses the bended structure to reduce the size of the normal quarter-wavelength two-arm BL coupler. The second one improves the bandwidth by adding external compensated networks, which are also folded for size reduction. In this study, the performances of these BL couplers are examined, theoretically and experimentally.**

***Index Terms*—Branch-line coupler, finite-ground coplanar-waveguide structure.**

I. INTRODUCTION

BRANCH-LINE (BL) couplers play important roles in implementing 90° power dividers and combiners. They are fundamental parts of microwave circuits such as balanced amplifiers, balanced mixers, image rejection mixers, frequency discriminators, and circularly polarized antennas. A basic BL coupler is formed by four quarter-wavelength ($\lambda/4$) transmission lines, thus its size is quite large and its bandwidth is relatively limited. BL couplers have been implemented using the stripline [1], microstrip-line [2], multilayer [3], and double-sided [4], [5] structures.

BL couplers were also realized by the uniplanar structures. Hirota *et al.* [6] proposed a reduced-size BL coupler by using the combination of shorter high-impedance coplanar-waveguide (CPW) lines and shunt lumped capacitors. Its size may be drastically reduced, but the uniplanar feature of CPW structure would be destroyed by the introduction of shunt metal-insulator-metal capacitors. Ho *et al.* [7], [8] implemented a uniplanar BL coupler by using a coupled rectangular slotline ring for coupling and bandwidth improvement. Its bandwidth can be increased up to 40%, but its input and output ports are realized by the slotline structures which need additional coplanar waveguide-to-slotline transition structures for connection to the other circuit components. Alternatively, Heimer *et al.* [9] utilized the asymmetrical coplanar strips to implement the uniplanar BL coupler. The BL couplers in [7]–[9] all have $\lambda/4$ line sections whose sizes are relatively large.

Recently, the finite-ground coplanar-waveguide (FGCPW) structure received considerable attention in implementing a variety of circuit components such as filters [10], antenna feeders [11], and reversed-phase hybrid-ring couplers [12], [13]. The FGCPW line has the merits of the conventional coplanar waveguide such as easy connection of series and shunt components [10]. The FGCPW structure may achieve the high-density integration by reducing the real estate of ground planes [11], and can provide an additional parameter, the width of the ground plane, for adjusting the line impedance. The FGCPW structure may overcome the parasitic parallel-plate waveguide-mode problem associated with the conventional backside-metallization coplanar waveguide [10]. Another attractive feature of FGCPW line is that a crossover of signal strip and ground plane can easily be achieved, and this crossover is essential in providing a 180° phase shift for a reversed-phase hybrid-ring coupler [12], [13]. In this study, two uniplanar BL couplers (Figs. 1 and 2) realized by FGCPW structures are

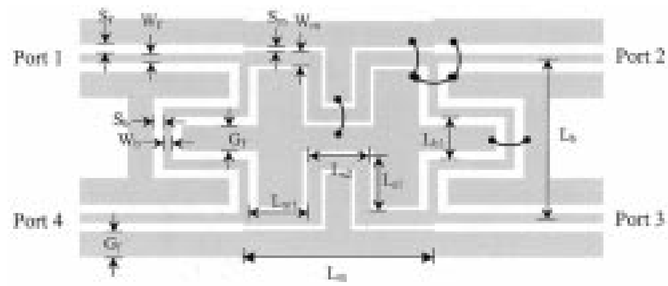

Fig. 1. Configuration of bended FGCPW BL coupler. ($W_m = 1.1$ mm, $S_m = 0.4$ mm, $W_f = W_b = 0.7$ mm, $S_f = S_b = 0.8$ mm, $L_m = 15.12$ mm, $L_{m1} = 6.56$ mm, $L_{b1} = 3.6$ mm, $L_b = 12.9$ mm, $L_{s1} = 4.5$ mm, $L_{s2} = 5$ mm, $G_f = 2$ mm.)

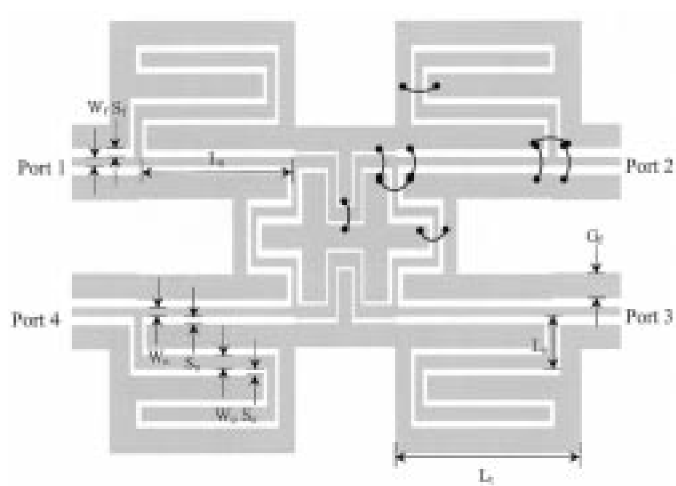

Fig. 2. Configuration of bended and folded broadband BL coupler. ($W_f = W_n = S_n = 0.7$ mm, $S_f = 0.8$ mm, $W_o = 0.7$ mm, $S_o = 0.7$ mm, $L_n = 23$ mm, $L_o = 4.5$ mm, $L_t = 27.8$ mm, $G_f = 2$ mm. Dimensions for bended main and branch parts are the same as in Fig. 1.)

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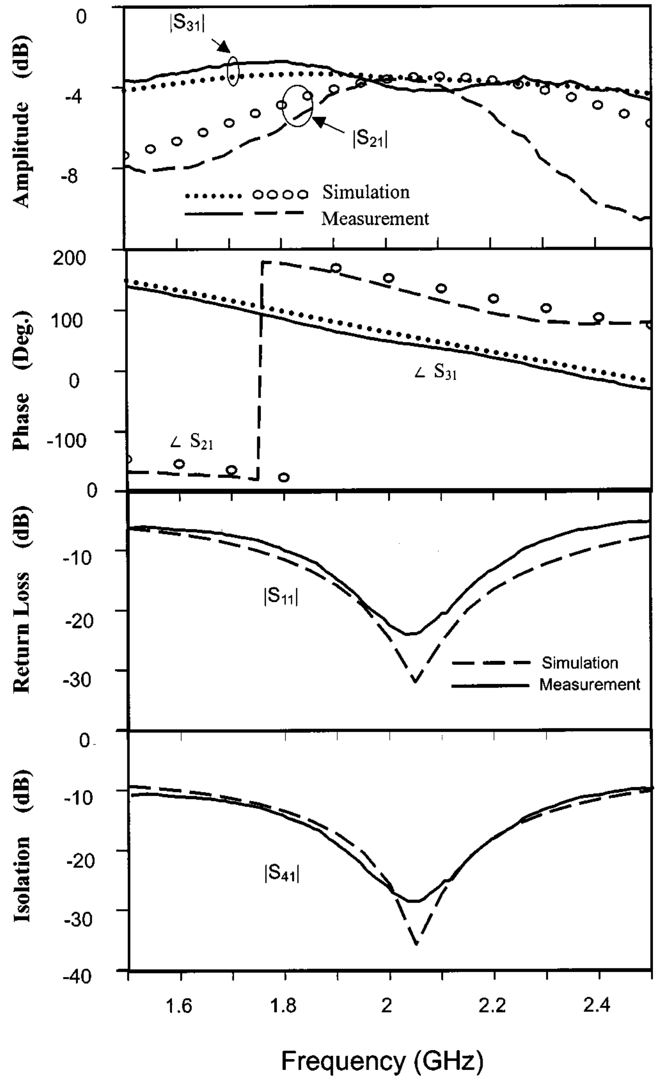

Fig. 3. S-parameters of bended FGCPW BL coupler shown in Fig. 1.

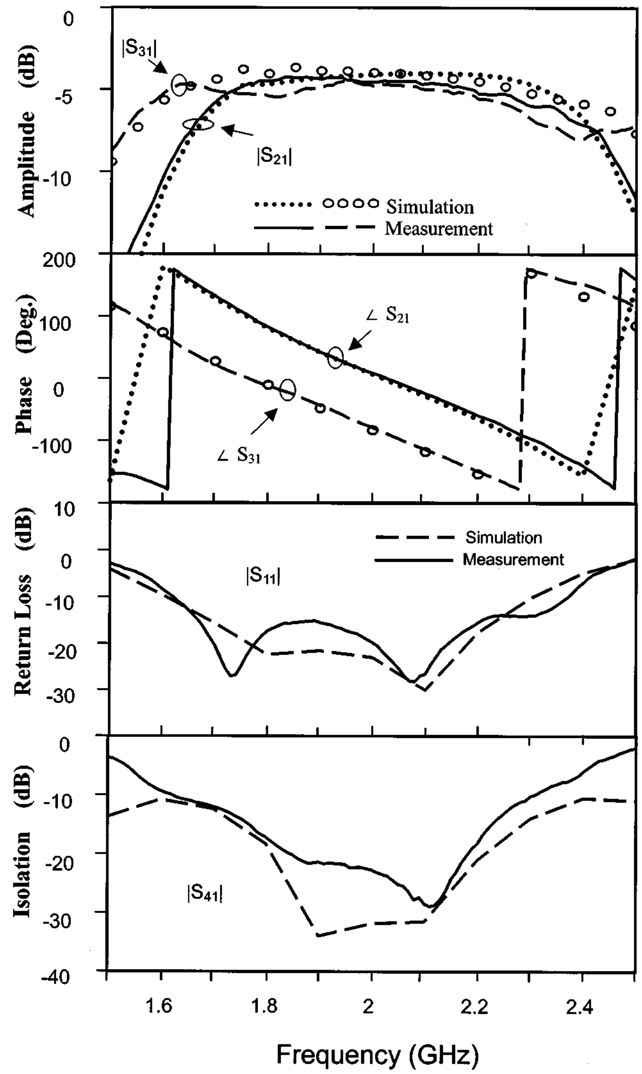

Fig. 4. S-parameters of bended and folded broadband BL coupler shown in Fig. 2.

proposed and examined. The main and branch FGCPW lines are bended to achieve the goal of size reduction. The external compensated networks consisting of series $\lambda/4$ transformers shunted by half-wavelength ($\lambda/2$) folded open stubs are also introduced in the coupler structure of Fig. 2 for improving its bandwidth.

II. Branch-Line Coupler Structures

The essential parts of a normal BL coupler are the four $\lambda/4$ main and branch transmission lines. Fig. 1 shows the proposed bended BL coupler based on the FGCPW structure. This is a modified version of the normal BL coupler which consists of straight $\lambda/4$ FGCPW lines. Here, the main lines and branch lines of the proposed coupler (Fig. 1) are bended so as to achieve the goal of size reduction. The discontinuity effects associated with the bended structures are minor and the total lengths of bended main and branch lines are still around $\lambda/4$.

Based on the core bended structure shown in Fig. 1, a novel FGCPW BL coupler (Fig. 2) to give better bandwidth is also proposed. In order to design a coupler with 25% bandwidth, compensated networks at four ports [1] are added in the design process. Each compensated network consists of a series $\lambda/4$ transformer which is shunted by a $\lambda/2$ open stub. For size reduction, each external $\lambda/2$ open stub is folded to form the structure shown in Fig. 2. Here, the length of each folded line section is again around $\lambda/2$, indicating that the discontinuity effects due to folded structures are still not important.

In this study, the coupler's bandwidth is described by the conditions on the S-parameters: $|S_{11}| < -15$ dB, $|S_{41}| < -15$ dB, $|S_{21}| - |S_{31}| \leqq \pm 1$ dB, and $\angle S_{21} - \angle S_{31} \leqq 90° \pm 10°$.

The FGCPW BL couplers shown in Figs. 1 and 2 are fabricated on the FR4 substrate ($\varepsilon_r = 4.6$, $\tan\delta = 0.022$, $h = 1.6$ mm) and designed at center frequency 2 GHz. In this study, the characteristic impedances of the feed lines are chosen as 100 Ω for easy realization on the FR4 substrate. The impedances of main lines and branch lines are 70.7 Ω and 100 Ω, and the impedances of the transformers and open stubs in compensated networks of Fig. 2 are 97 Ω and 84.75 Ω, respectively. For the feed line, the width W_f of the center conductor is 0.7

mm and the slot width S_f is 0.8 mm. All FGCPW's have the ground-plane width G_f of 2 mm.

For the proposed structures shown in Figs. 1 and 2, bond wires are added to suppress the unwanted coupled-slotline mode excited at discontinuities. For simplicity and by symmetry, only the bond wires in the first quadrant are shown in Figs. 1 and 2. Practically, additional bond wires should also be added in the other quadrants.

III. Results

The proposed BL couplers (Figs. 1 and 2) are designed based on the quasistatic characteristic-impedance formulas for FGCPW lines [14]. They are then simulated by the tool Zeland IE3D, including the simulation of bond wires. The S-parameters are measured by using the HP8510B network analyzer together with the TRL (through-reflect-line) calibration technique.

For the bended BL coupler shown in Fig. 1, its size may be reduced to 60% of the normal λ/4 BL coupler without bending and its bandwidth is 14%. Fig. 3 shows the simulated and measured results for the S-parameters. The return loss is less than -15 dB in the range 1.9$\sim$2.17 GHz. The difference between $|S21|$ and $|S31|$ is under ± 1 dB within 1.9$\sim$2.18 GHz and the phase difference between S_{21} and S_{31} is within 90°$\pm$5° in the frequency range 1.75$\sim$2.26 GHz.

For the bended and folded broadband BL coupler (Fig. 2), its size may be reduced to 1/4 of the corresponding broadband structure without bending and folding. Fig. 4 shows the simulated and measured results for the structure shown in Fig. 2. In the range of 1.82$\sim$2.31 GHz, the difference between $|S_{21}|$ and $|S_{31}|$ is under ± 1 dB, and the phase difference between S_{21} and S_{31} is within 90°$\pm$5°. The isolation response and return loss are also shown in Fig. 4. The bandwidth of the structure (Fig. 2) is 22%, which is larger than that (14%) of the structure shown in Fig. 1. In comparison with the normal BL coupler with non-bended $\lambda/4$ line sections which has a bandwidth of 15%, the improvement of the bandwidth (22%) is accompanied by an expansive cost of size increase (with factor around 3).

IV. Conclusions

Two FGCPW BL couplers have been proposed. The first BL coupler (Fig. 1) is realized by using the bended FGCPW structure. The area of this bended BL coupler (Fig. 1) may be reduced up to 40%, but its bandwidth is narrower (14%). For the bended and folded broadband BL coupler (Fig. 2), its size is reduced to 1/4 of the corresponding broadband design without bending and folding, and its bandwidth is about 22%. The proposed BL couplers are suitable for MIC/MMIC applications.

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