Novel Uniplanar 180° Hybrid-Ring Couplers with Spiral-Type Phase Inverters

Chih-Wai Kao and Chun Hsiung Chen

***Abstract*—Novel uniplanar 180° hybrid-ring couplers consisting of coplanar-waveguide (CPW) rings and spiral-type phase inverters are proposed. In this study, CPW phase inverters with single-spiral and twin-spiral type slotline short stubs are utilized to design the hybrid-ring couplers. Specifically, two hybrid-ring couplers with 33% (single-spiral type) and 40% (twin-spiral type) bandwidths are implemented and examined, theoretically and experimentally.**

***Index Terms*—Spiral-type phase inverter, 180° hybrid-ring coupler.**

I. INTRODUCTION

HYBRID-RING couplers are fundamental components of microwave circuits such as balanced mixers, phase shifters, and feed networks in antenna arrays. The rat-race hybrid-ring coupler is the most common one, but its area is undesirably large and its bandwidth is also limited due to the use of a $3\lambda_g/4$ line segment.

In recent years, uniplanar transmission lines such as coplanar waveguide (CPW), slotline, and coplanar stripline are widely used in microwave integrated circuit (MIC) and monolithic microwave integrated circuit (MMIC). Uniplanar lines have the merits such as easy realization of short-circuit end, no need for via holes, low dispersion, and easy integration with active components or lump elements. Using uniplanar line structures, several 180° hybrid-ring couplers have been reported [1]–[3]. In those papers, suitable wideband open circuits have been properly incorporated in the hybrid design, since the bandwidth of a hybrid is mainly determined by the performance of these open circuits. The simplest open circuit structure is the quarter-wavelength short-circuit stub, but its bandwidth is quite limited. To improve the bandwidth, some modified structures have been proposed, such as to use the twin short stubs or radial stubs [4], [5], but their sizes are still large.

Recently, a twin-spiral slotline short-stub structure was proposed to reduce the size of CPW-to-slotline transition [6]. Based on the same idea, novel 180° hybrid-ring couplers with single-spiral and twin-spiral type phase inverters are proposed and carefully examined. These hybrid-ring couplers may achieve the goal of small size and good bandwidth, thus, may find applications in MIC and MMIC.

Manuscript received June 13, 2000; revised August 1, 2000. This work was supported by the Ministry of Education and National Science Council of Taiwan, R.O.C., under Grants 89-E-FA06-2-4 and NSC 89-2213-E-002-047.

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Publisher Item Identifier S 1051-8207(00)09716-6.

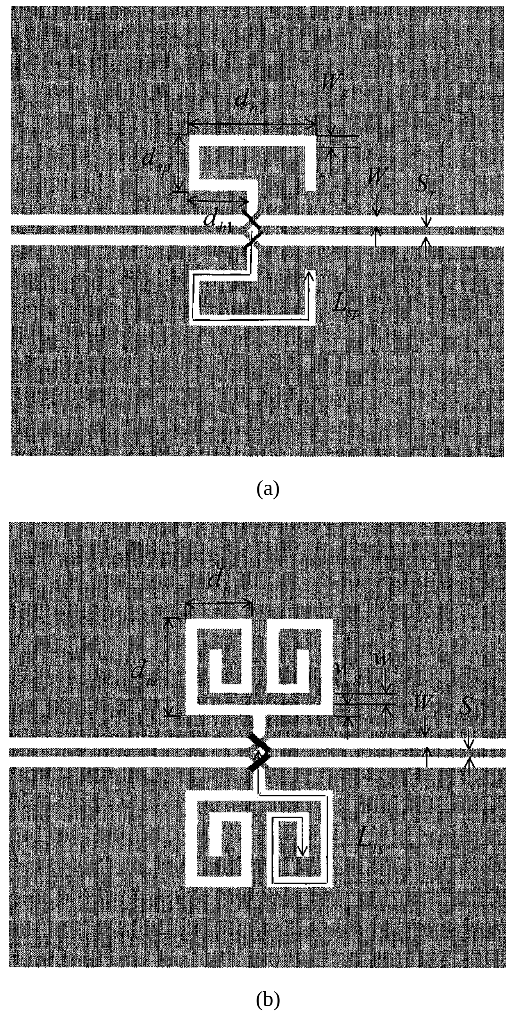

Fig. 1. Uniplanar phase inverters: (a) single-spiral type and (b) twin-spiral type. ($W_r = 0.76$ mm, $S_r = 1.15$ mm, $W_g = 1.15$ mm, $d_{h1} = 6$ mm, $d_{h2} = 13.15$ mm, $d_{\rm sp} = 5.5$ mm, $L_{\rm sp} = 31.76$ mm, $W_s = 1$ mm, $d_{\rm ts} = 10.6$ mm, $d_h = 6$ mm, $L_{\rm ts} = 40.03$ mm.)

II. SPIRAL-TYPE UNIPLANAR PHASE INVERTERS

Reverse phase along a CPW line can be achieved by using either one of the uniplanar CPW phase inverters, as shown in Fig. 1. In these phase inverters, the signal strip of left CPW is connected to the ground planes of right CPW and the signal strip of right CPW is connected to the ground planes of left CPW by two bond wires. Here, an open circuit at the CPW crossover region is realized by using either the single-spiral or twin-spiral type slotline short stub, which is the modified version of the conventional $\lambda_g/4$ short-stub structure. The single-spiral type phase inverter [Fig. 1(a)] has the advantages of small size and low radiation loss but its bandwidth is relatively limited. To improve the bandwidth and also to keep the size small, the twin

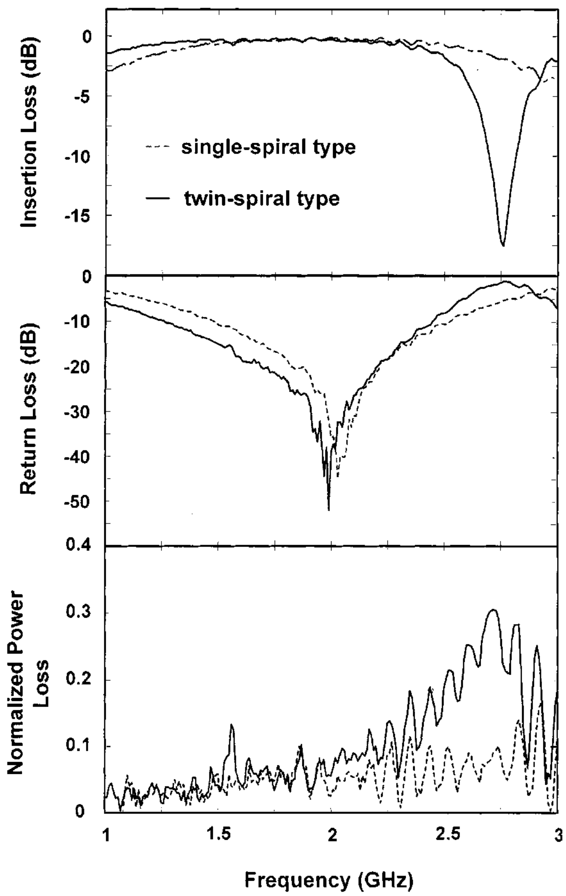

Fig. 2. Measured insertion loss, return loss, and normalized power loss for single-spiral and twin-spiral type phase inverters.

$\lambda_g/4$ short-stub structure is modified [6] to form the twin-spiral type uniplanar phase inverter, as shown in Fig. 1(b). Since the twin-spiral section is symmetric and is fed by a slotline, the two half parts of the twin-spiral section are excited with a 180° phase difference. To compensate the effect of slotline bend, the length of spiral-like stub should be slightly longer.

In this study, both single-spiral and twin-spiral type CPW phase inverters are fabricated on the FR4 substrate ($\varepsilon_r = 4.3$, $\tan\delta = 0.022$, thickness $h = 1.6$ mm). They are measured by the HP8510B network analyzer together with the TRL (through-reflect-line) calibration technique. Theoretically they are also simulated by the IE3D software, which is based upon an integral-equation and method-of-moment algorithm. Fig. 2 shows the measured results for both single-spiral and twin-spiral type phase inverters. The corresponding simulated results are in good agreement with the measured ones and are not shown in Fig. 2. The bandwidth of twin-spiral type phase inverter is greater than that of single-spiral type phase inverter, as expected.

Fig. 2 also compares the normalized power losses of single-spiral and twin-spiral type phase inverters. They are calculated by the equation $1 - |S_{11}|^2 - |S_{21}|^2$. The normalized power loss of single-spiral type inverter is lower than that of twin-spiral type inverter due to the cancellation effect of E-field distributions. However, the radiation loss of the twin-spiral type phase inverter is still smaller than that of the radial-type phase inverter [7] because of its out-of-phase excitation.

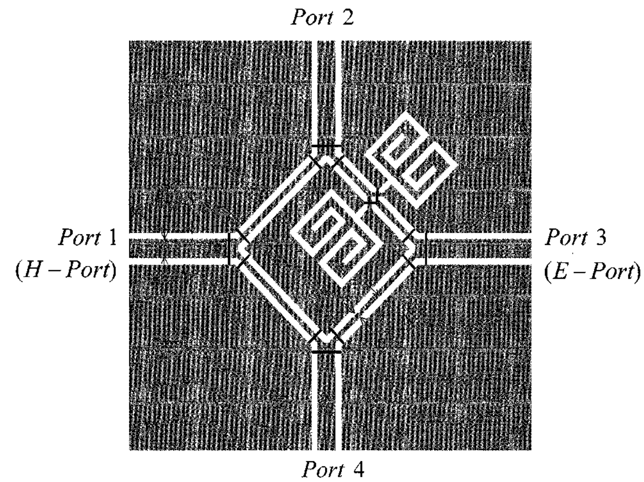

Fig. 3. Configuration of twin-spiral type hybrid-ring coupler. ($Z_0 = 75\ \Omega$, $W_f = 3$ mm, $S_f = 1.15$ mm, $W_r = 0.76$ mm, $S_r = 1.15$ mm.)

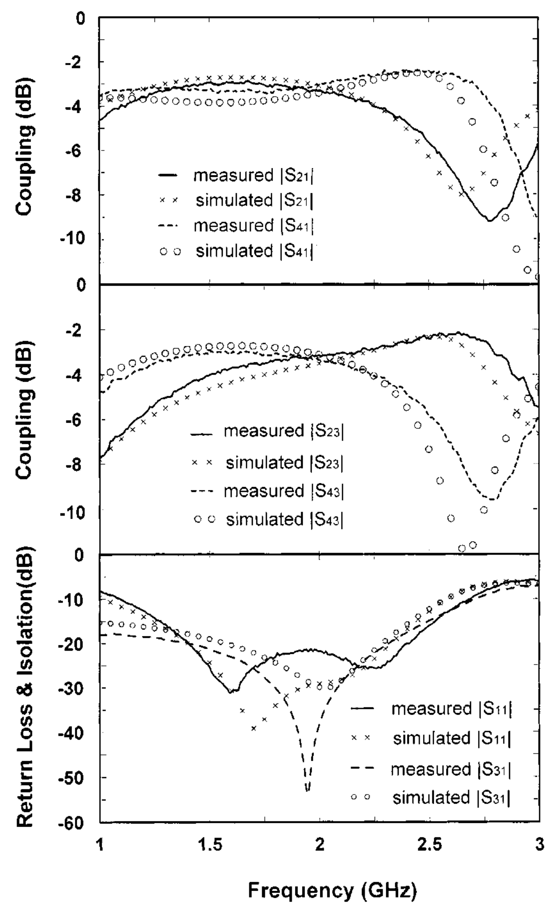

Fig. 4. Measured and simulated results for single-spiral type hybrid-ring coupler.

III. Uniplanar 180° Hybrid-Ring Couplers

Fig. 3 shows the proposed novel uniplanar 180° hybrid-ring coupler with twin-spiral type phase inverter. The single-spiral

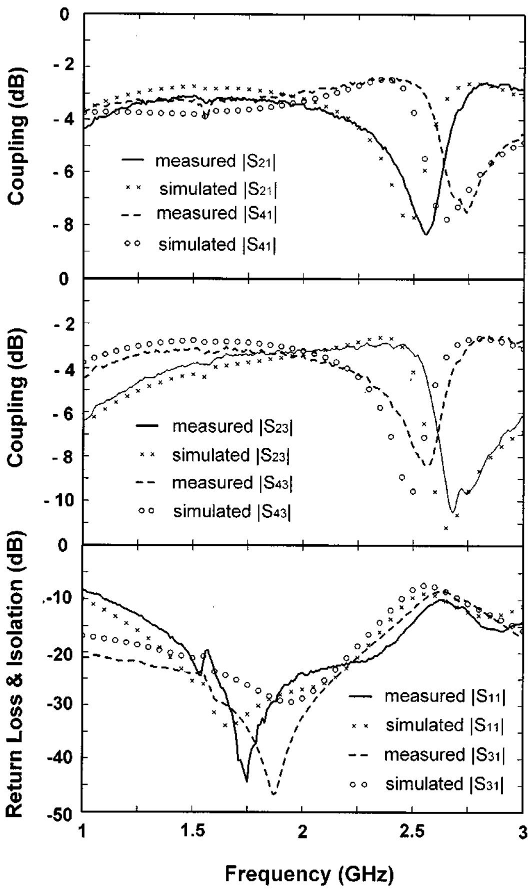

Fig. 5. Measured and simulated results for twin-spiral type hybrid-ring coupler.

type hybrid-ring coupler has the same circuit layout except that the twin-spiral type phase inverter is replaced by the single-spiral one. The impedance of the ring is given by $Z_{\rm ring} = \sqrt{2}Z_0$, where Z_0 is the port impedance which is chosen as 75 Ω. The length of each arm is quarter wavelength at the center frequency and the dimensions of both phase inverters are the same as those of Fig. 1. The bondwires at the T-junctions are used to suppress the undesired coupled slotline mode generated at these discontinuities.

In this study, both single-spiral and twin-spiral type hybrid-ring couplers are designed at center frequency 2 GHz and fabricated on the FR4 substrate. In simulation, the coupler (four-port network) is divided into four T-junctions (three-port networks) and four two-port networks. These two-port and three-port networks are simulated separately by the IE3D software and the results are cascaded and combined to analyze the performance of the hybrid-ring coupler. The measured and simulated results of the hybrid-ring coupler with single-spiral type phase inverter are shown in Fig. 4. The measured results agree well with the simulated ones.

Fig. 5 shows the simulated and measured results for the hybrid-ring coupler with twin-spiral type phase inverter. The isolation between E-port and H-port is greater than 30 dB at center frequency, and is greater than 15 dB from 1 GHz to 2.42 GHz. The H-port power dividing unbalance is less than 1 dB from 1 GHz to 2.15 GHz, and the E-port power dividing unbalance is less than 1 dB from 1.35 GHz to 2.2 GHz. The in-phase and out-of-phase phase differences are less than 15° from 1 GHz to 2.5 GHz and 1 GHz to 2.42 GHz, respectively.

The bandwidth of twin-spiral type hybrid-ring coupler is 40% which is larger than that (33%) of single-spiral type hybrid-ring coupler. These results indicate that the performance of the hybrid-ring coupler is mainly determined by the performance of the associated phase inverter.

IV. Conclusion

In this study, novel uniplanar 180° hybrid-ring couplers with single-spiral and twin-spiral type uniplanar phase inverters have been proposed. These hybrid-ring couplers have the bandwidths of 33% (single-spiral type) and 40% (twin-spiral type) at center frequency 2 GHz, and present good isolation between E-port and H-port. Further compact hybrid-ring coupler may be achieved by using more turns in the single-spiral or twin-spiral sections, but the bandwidth would be slightly reduced. Its reduced size and simple design properties are attractive in MIC/MMIC applications.

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