Progress In Electromagnetics Research Letters, Vol. 23, 129–135, 2011

A NOVEL MINIATURIZED MICRO-STRIP SIX-PORT JUNCTION

X.-T. Fang, X.-C. Zhang, and C.-M. Tong †

Missile Institute of Air Force Engineering University
Sanyuan, Shanxi 713800, China

Abstract—A novel miniaturized micro-strip six-port junction is presented. The new structure effectively reduces the occupied area to 25% of the conventional six-port junction due to two open loaded stubs. The design is validated both by using momentum of Advanced Design System and by measurement.

1. INTRODUCTION

During recent years, there has been great interest in six-port circuits due to their abilities of measuring the phase difference between two input signals by means of power readings at four output ports. Various six-port junctions have been proposed and implemented with distributed transmission lines and lumped elements according to Engen's design criteria [1–5], and they have been used in application of wireless communication systems and Radar systems, extensively. In [2], a novel six-port circuit based on four 90° hybrid couplers was designed. In [4], a six-port reflectometer consisting of four 0°/180° micro-strip ring couplers was presented. They all have suitable structures but occupy too large area. In [5], one miniature lumped six-port reflectometer was proposed. However, when the operating frequency goes up, the signal loss due to lumped elements becomes high.

In this paper, a miniaturized six-port junction based on micro-strip technology is introduced. It adopts the conventional constitution which is composed of a 3 dB Wilkinson power divider and three 90°

Received 23 March 2011, Accepted 26 April 2011, Scheduled 2 May 2011
Corresponding author: Xin-Tian Fang (fangxintian@126.com).
† X.-C. Zhang is also with Xidian University, Xi'an 710071, China. C.-M. Tong is also with State Key Laboratory of Millimeter Wave, Nanjing, 210096, China.

hybrid couplers [6], but its occupied area is only 25% of that of the conventional case. Simulation and measurement results show that the proposed six-port junction has good performance.

2. CIRCUIT DESIGN

The schematic layout of the proposed six-port junction is shown in Fig. 1. It is composed of one miniaturized Wilkinson power divider and three miniaturized 90° hybrid couplers. They all have $\lambda/4$ transmission lines, which utilize two high-low impedance shunt stubs to reduce size. In order to develop a miniaturized six-port junction, the power divider and 90° hybrid coupler with an equivalent 90° electrical length should be effectively synthesized. As shown in Fig. 2, we can easily deduce the relation of Z_0, θ, Z_a, θ_a, Z_b and θ_b [7]. When θ is $\pi/4$, we get

$$Z_a = Z_0 \Big/ \left(\sqrt{2}\sin\theta_a\right) \tag{1}$$

$$Z_b = Z_0 \tan\theta_b \Big/ \left(\sqrt{2}\cos\theta_a - 1\right) \tag{2}$$

where Z_a, Z_b and Z_0 are the characteristic impedance of transmission lines, and θ_a, θ_b, θ are electrical lengths. In order to design the power divider properly, we choose the circular arc loaded by four open

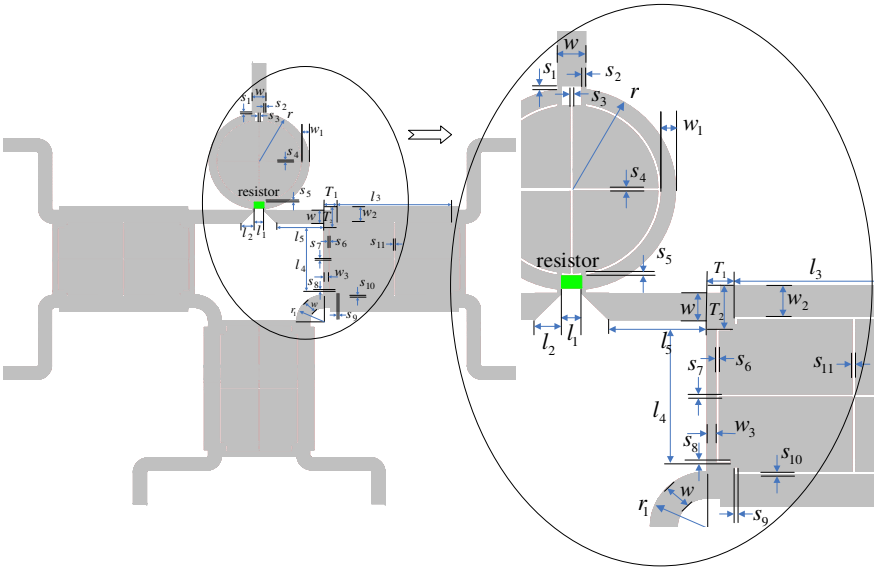

Figure 1. Proposed six-port junction.

quarter circles, which replaces a pair of $\lambda/4$ transmission lines with characteristic impedance of $Z_T = \sqrt{2}Z_0$ to minimize the occupied area and decrease electromagnetic coupling of micro-strip lines. By optimizing the width (w_1) of the arc and the radius (r) of the circle, it is easy to get the size of power divider. In the process of designing 90° hybrid coupler, we keep the four T joints of conventional 90° hybrid coupler and change two pairs of $\lambda/4$ transmission lines with characteristic impedance of $Z_P = Z_0$ and $Z_R = Z_0/\sqrt{2}$ into two pairs of shorter $\lambda/4$ transmission lines embedded with four rectangles microstrip lines. In the case, miniaturized 90° hybrid coupler can be determined according to four parameters (the width (w_2, w_3) and the length (l_3, l_4)).

The proposed six-port junction is designed based on the miniaturized power divider and 90° hybrid couplers mentioned above. The dimensions of the designed model are: $w = 1.57\,\text{mm}$, $w_1 = 0.82\,\text{mm}$, $w_2 = 1.87\,\text{mm}$, $w_3 = 0.53\,\text{mm}$, $r = 6.00\,\text{mm}$, $r_1 = 3.28\,\text{mm}$, $l_1 = 1.17\,\text{mm}$, $l_2 = 1.57\,\text{mm}$, $l_3 = 13.80\,\text{mm}$, $l_4 = 8.06\,\text{mm}$, $l_5 = 5.66\,\text{mm}$, $T_1 = 1.57\,\text{mm}$, $T_2 = 2.56\,\text{mm}$, $s_i = 0.2\,\text{mm}$ $(i = 1, 2, \ldots, 11)$. All slots, gaps, and the high impedance lines have the same width of 0.2 mm and are easy for fabrication. The three 90° hybrid couplers have the same size. In these values, l_3, l_4 and r mainly determine the size of miniaturized six-port junction.

Compared with a usual $\lambda/4$ transmission line which has a length about 23 mm, the miniaturized 90° hybrid coupler and power divider occupy about 21% and 27% of that of the conventional case. Eventually, the proposed six-port junction is fabricated on an

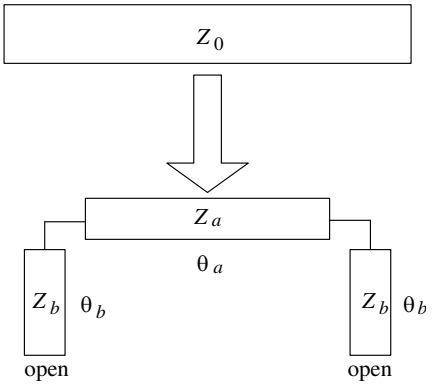

Figure 2. Micro-strip line loaded by two open stubs.

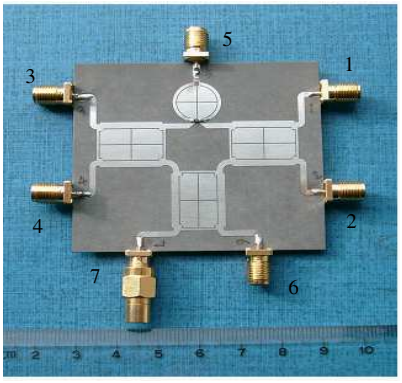

Figure 3. Photo of the six-port junction.

$5.5 \times 6.1\,\text{cm}^2$ (in the conventional case it is about $11 \times 12\,\text{cm}^2$) substrate with relative permittivity of 2.2 and thickness of 0.508 mm, as shown in Fig. 3.

3. SIMULATION AND MEASUREMENT RESULTS

Simulation was accomplished using momentum of Advanced Design System (ADS), which is an electromagnetic wave simulator based on the method of moment (MoM). Measurement was carried out by an Agilent 37377C network analyzer.

Figures 4 and 5 show the simulated and measured S-parameters

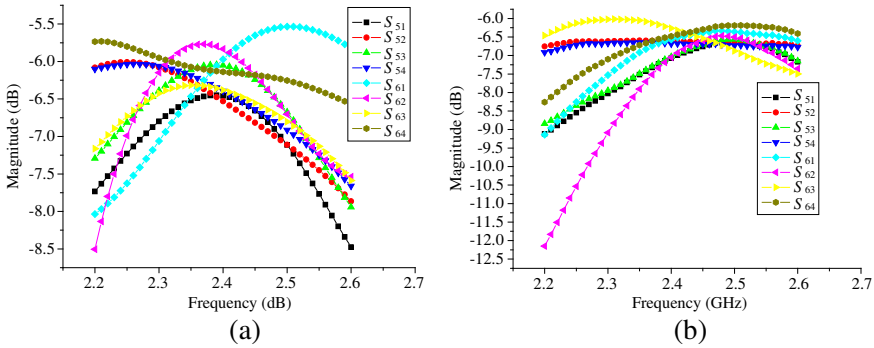

Figure 4. S-parameters magnitude (S_{5i}, S_{6i}, i from 1 to 4) of the proposed six-port junction. (a) The simulated. (b) The measured.

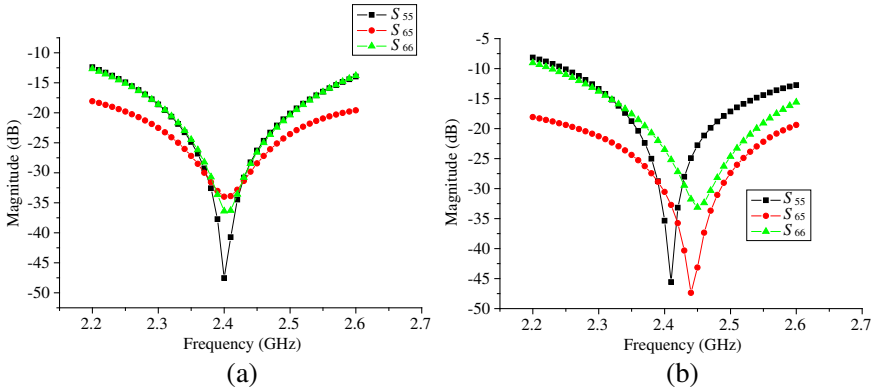

Figure 5. S-parameters magnitude (S_{55}, S_{65}, S_{66}) of the proposed six-port junction. (a) The simulated. (b) The measured.

magnitude of the proposed six-port junction. From the simulated and measured results, we can clearly observe that the transmission coefficients of input ports ($5 \sim 6$) to the output ports ($1 \sim 4$) is close to the theoretical predicted value -6 dB, and the measured results are less than -6.7 dB, which is a little lower than the simulated result of -6.5 dB at the central frequency. At the same time, it can be noted that the return loss and isolation of the two input ports 5 and 6 are lower than -25 dB at the center frequency 2.4 GHz and lower than -10 dB over the entire operating frequency band of interest (2.2–2.6 GHz), which means that the input ports are well matched and isolated.

The proposed six-port junction has not only good magnitude properties, but also fine phase relationship. Figs. 6 and 7 show the simulated and measured phases of $S_{51} \sim S_{54}$ and $S_{61} \sim S_{64}$ of the proposed six-port junction. The phase alteration is linear over the operating frequency band. At the center frequency of 2.4 GHz, the measured phase difference of the adjoining output ports is given by

$$ang(S_{51} - S_{52}) = -19.05^\circ - (-108.58^\circ) = 89.53^\circ \quad (3)$$

$$ang(S_{53} - S_{54}) = -20.23^\circ - (-109.47^\circ) = 89.24^\circ \quad (4)$$

$$ang(S_{61} - S_{62}) = -91.13^\circ - (-1.03^\circ) = -90.10^\circ \quad (5)$$

$$ang(S_{63} - S_{64}) = 178.47^\circ - (-91.62^\circ) = 270.09^\circ \quad (6)$$

which indicates that the maximum phase error is less than 1°.

There are some slight differences of magnitude and phase between the simulated and measured results, which may due to the fabrication tolerances and the infinite dielectric and ground planes assumed in the

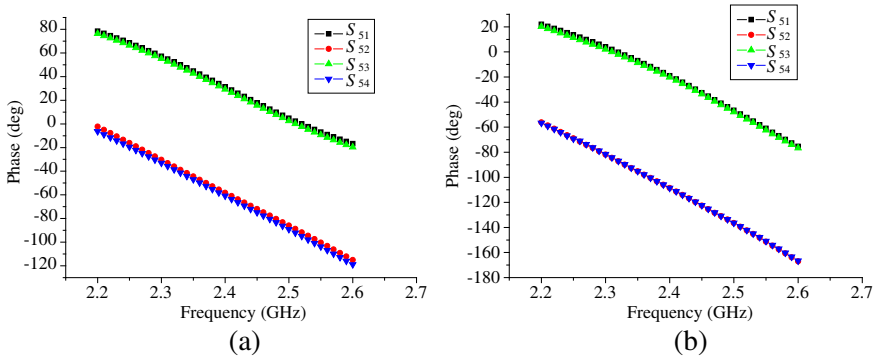

Figure 6. S-parameters phase (S_{5i}, i from 1 to 4) of the proposed six-port junction. (a) The simulated. (b) The measured.

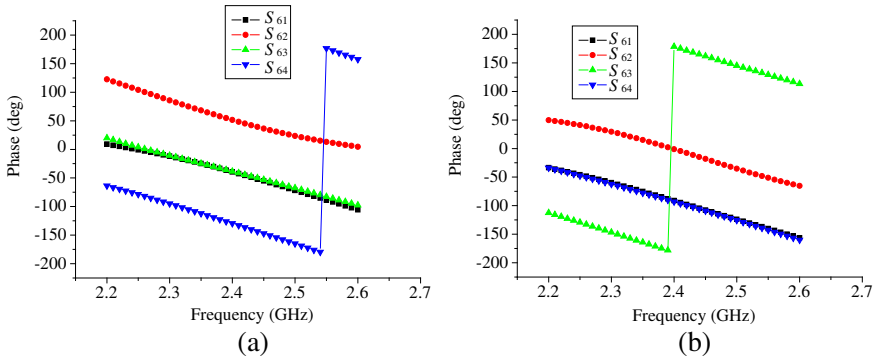

Figure 7. S-parameters phase (S_{6i}, i from 1 to 4) of the proposed six-port junction. (a) The simulated. (b) The measured.

simulation. Besides this, simulated and measured results are in fairly good agreement.

4. CONCLUSION

A novel miniaturized six-port junction based on micro-strip technology is presented. Owing to the open loaded stubs, the new structure not only has good performance, but also effectively reduces occupied area to 25% of the conventional case. The proposed six-port junction is compact, easy for fabrication and applicable to microwave system applications.

ACKNOWLEDGMENT

The authors wish to thank State Key Lab. of Millimeter Waves for fund support (K200907).

REFERENCES

1. Engen, G. F., "An improved circuit for implementing the six-port technique of microwave measurement," *IEEE Trans. Microwave Theory Tech.*, Vol. 25, 1080–1083, 1997.
2. Li, C., H. Zhang, and P. Wang, "A novel six-port circuit based on four quadrature hybrids," *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 20, 128–132, 2010.

3. Mohra, A. S., "Six-port reflectometer based on four 0°/180° microstrip ring couplers," *Microwave Opt. Technol. Lett.*, Vol. 40, 167–170, 2004.
4. Yao, J. J. and S. P. Yeo, "Six-port reflectometer based on modified hybrid coupler," *IEEE Trans. Microwave Theory Tech.*, Vol. 56, 493–498, 2008.
5. Bilik, V., V. Raffai, and J. Bezek, "Miniature broadband lumped six-port reflectometers," *J. Commun.*, Vol. 42, 7–14, 1991.
6. Yu, J. and Y. Kim, "Performance analysis for various structures of six-port phase correlator using hybrid coupler, power divider and rat-race ring coupler," *International Symposium on Computer Science and Its Applications*, 243–246, 2008.
7. Vogel, R. W., "Analysis and design of lumped-and lumped-distributed-element directional couplers for MIC and MMIC applications," *IEEE Trans. Microwave Theory Tech.*, Vol. 40, 253–262, 1992.