Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
June 2012, 19(Suppl. 1): 29–32
www.sciencedirect.com/science/journal/10058885
The Journal of China Universities of Posts and Telecommunications
http://jcupt.xsw.bupt.cn

Simulation study on the characteristics of 3 GHz microstrip racetrack hybrid ring

SHAN Jiang-dong, RU Yu-xing, WU Ge, TIAN Xiao-jian (✉)

College of Electronic Science and Engineering, Jilin University, Changchun 130012, China

Abstract

This paper theoretically analyzed the characteristics of the microstrip hybrid ring. 3 dB standard microstrip hybrid ring and racetrack hybrid ring, whose working frequency is 3 GHz, have been designed on a rectangular substrate. Using high frequency structure simulator (HFSS) software as tool for simulation, the s-parameter data is comparatively studied. The experimental results showed that the overall performance of the designed racetrack microstrip hybrid ring is superior to the ordinary standard microstrip hybrid ring.

Keywords racetrack hybrid ring, microstrip circuit, simulation experiment

1 Introduction

Microwave hybrid ring is one of the most important passive components in microwave circuits and is widely used. Hybrid ring is composed by a circular transmission line and four branch lines. It is a typical 3 dB 180° directional coupler. Its main applications include the power divider, power combiner, balanced mixers, push-pull amplifier, standard phase shifters, antenna array feed network and so on [1–2]. Microstrip hybrid ring has gradually replaced the waveguide hybrid ring for its advantages of small size, light weight, easy processing. The main direction of the microstrip hybrid ring is broadband and miniaturization [3]. The standard shape of microstrip hybrid ring is shown as Fig. 1. The angle of the four branch line is 60 degrees, so the branch lines would be the turning corner, if the hybrid ring is designed on a rectangular substrate. And voltage standing wave ratio (VSWR) would be increased because of the turning corners. To overcome this shortcoming, a new microstrip hybrid ring named racetrack is designed, shown in Fig. 2. This paper theoretically analyzed the characteristics of the microstrip hybrid ring. 3 dB standard microstrip hybrid ring and racetrack hybrid ring, whose work frequency is 3 GHz, have been designed on a rectangular substrate. Using HFSS software as tool or simulation, the s-parameter data is comparatively studied.

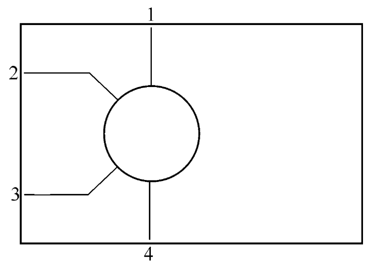

Fig. 1 Standard microstrip hybrid ring on rectangular substrate

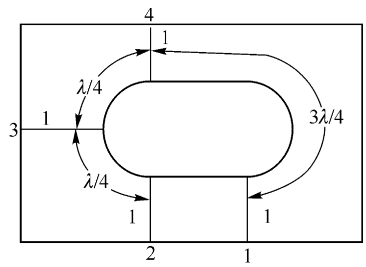

Fig. 2 Racetrack microstrip hybrid ring on rectangular substrate

2 Theoretical analysis

Microstrip is a kind of planar transmission line, and is widely used in hybrid microwave integrated circuit (HMIC) and monolithic microwave integrated circuit (MMIC). It

Received date: 30-03-2012
Corresponding author: TIAN Xiao-jian, E-mail: tianxj@jlu.edu.cn
DOI: 10.1016/S1005-8885(11)60474-3

can also be used to form the matching network and microwaves devices. In this paper, microstrip is adopted to design a hybrid ring [4].

2.1 S-parameters of microstrip hybrid ring

Fig. 2 shows that the zoning line of racetrack microstrip hybrid ring is composed of two $\lambda/2$ semi-circles and two $\lambda/4$ straight microstrip lines. This design shape can ensure that each branch line leads directly and eliminate the increasing proportion of VSWR which is brought about by the corner. The microstrip hybrid ring is a four-port network. We focus on the properties of the reflection of its port and the signal transmission between the different ports, and these properties are characterized by the s-parameters. Starting from the structural features and functional characteristics of the microstrip racetrack hybrid ring, and by selecting the appropriate reference plane, its $\boldsymbol{S}$ matrix can be obtained theoretically as Eq. (1) [5].

$$\boldsymbol{S}=\frac{-\mathrm{j}}{\sqrt{2}}\begin{bmatrix}0 & 1 & 1 & 0\\ 1 & 0 & 0 & -1\\ 1 & 0 & 0 & 1\\ 0 & -1 & 1 & 0\end{bmatrix} \tag{1}$$

2.2 Main design parameters of microstrip hybrid ring

Main design parameters of microstrip hybrid ring satisfy the following formulas.

$$Z_0=\frac{Z_0'}{\sqrt{\varepsilon_\mathrm{e}}} \tag{2}$$

$$Z_0'=60\ln\left(\frac{8h}{w}+\frac{w}{4h}\right);\quad w/h\leqslant 1 \tag{3}$$

$$Z_0'=\frac{120\pi}{\dfrac{w}{h}+2.42-0.44\dfrac{h}{w}+\left(1-\dfrac{h}{w}\right)^6};\quad w/h\geqslant 1 \tag{4}$$

$$\varepsilon_\mathrm{e}=\frac{\varepsilon_\mathrm{r}+1}{2}+\frac{\varepsilon_\mathrm{r}-1}{2}\left(1+\frac{10h}{w}\right)^{-\frac{1}{2}} \tag{5}$$

Where w is the microstrip line width; h is the thickness of the dielectric substrate; Z_0 is the characteristic impedance of the microstrip line; ε_e is the effective dielectric constant; Z_0' is air microstrip line characteristic impedance; ε_r is the dielectric constant of the substrate.

Using the above formulas, once Z_0 and ε_e are given, w/h can be calculated. Firstly, according to Z_0 and ε_r, Z_0' can be calculated by Eq. (1), $\left(Z_0'\right)_1=\sqrt{\varepsilon_\mathrm{r}}Z_0$, then take $\left(Z_0'\right)_1$ into Eq. (2) or Eq. (3) to obtain $(w/h)_1$; Secondly, take $(w/h)_1$ and ε_r into Eq. (4) to obtain $(\varepsilon_\mathrm{e})_1$. Thirdly, take $(\varepsilon_e)_1$ and Z_0 into Eq. (1) to recalculate Z_0', that is $\left(Z_0'\right)_2$. Using $\left(Z_0'\right)_2$ and repeating the above steps, we would get $(\varepsilon_\mathrm{e})_2$, until the difference between the two ε_e is in less than 1%.

2.3 Design process of microstrip hybrid ring

Firstly, we should determine the center frequency f_0 of the designed microstrip hybrid ring and initially selected substrate material (relative permittivity is ε_r), the thickness of the substrate h, the thickness of the conduct line t and the impedance of branch lines Z_0. Then from the values of ε_r, Z_0, t, we can calculate the impedance of zoning line Z_r, the width of branch lines u_1, the equivalent permittivity of branch lines ε_e1, the width of zoning line u_2 and the equivalent permittivity of zoning line ε_e2 [6]. The center radius of the zoning line R meets equation of $R=1.5c/2\pi f_0\sqrt{\varepsilon_\mathrm{e2}}$ (Where c is the speed of light in vacuum, the same below). So the outer ring radius of the zoning line meets equation of $R_1=R+u_2/2$, and the inner ring radius meets equation of $R_2=R-u_2/2$. In order to reduce the input VSWR, the branch lines are used as $\lambda/4$ impedance converter, and its length is $c/4f_0\sqrt{\varepsilon_\mathrm{e2}}$. According to Eq. (6), the non-dispersive upper limit frequency f_m would be calculated, and compared with center frequency f_0 to satisfy the formula of $f_\mathrm{m}-f_0>0$. So we can initially determine the scope of the solution in the simulation.

$$f_\mathrm{m}=\frac{0.95}{(\varepsilon_\mathrm{r}-1)^{1/4}}\sqrt{\frac{Z_0}{h}} \tag{6}$$

3 Experimental results and analysis

3.1 Modeling of the microstrip racetrack hybrid ring

With the above design process and using HFSS simulation platform, a kind of microstrip racetrack hybrid ring of 3 GHz center frequency is designed on a rectangular substrate. The main design data of the simulation model are as follows: substrate material is 99 ceramic, its relative permittivity is 0.000 2, and its height is 0.8 mm; conduct line material is copper, its thickness is $8\ \mu\mathrm{m}$; the characteristic impedance of branch lines Z_0 is