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A Miniaturized Directional Coupler Using Complementary Split Ring Resonator and Dumbbell-Like Defected Ground Structure

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Abstract—A novel microstrip coupled-line directional coupler is proposed in this paper. It is based on the introduction of a complementary split ring resonator and dumbbell-like defected ground structure on the coupled lines to strongly enhance the designed backward coupling. The designed frequency band is from 1.2 to 1.5 GHz. The coupler is fabricated and tested. The insertion loss is less than 3.5 dB. The simulated and measured return losses are better than -13.5 dB, and the isolation is higher than 20 dB across the operating band. The overall size of the coupler is 80 mm $\times$ 70 mm, which is about $0.36\lambda \times 0.32\lambda$ at the central frequency 1.35 GHz.

1. INTRODUCTION

Directional couplers are widely used in microwave integrated circuits (MICs) such as balanced mixers, balanced amplifiers, modulators and circularly polarized antennas [1]. Microstrip directional couplers are easily realised on a standard printed-circuit-board (PCB), but they are not compact due to the quarter-wave length of the coupled transmission lines. Several different configurations have been proposed to reduce the physical size of a directional coupler such as by use of artificial transmission lines [2, 3], open stubs [4], synthesized coplanar waveguide [5], substrate integrated waveguide [6, 7], periodical patterned ground structure [8, 9].

Defected ground structure (DGS) incorporated in the ground plane of microstrip transmission lines, which disturbs its current distribution and can give rise to increasing effective capacitance and inductance, is one of the most interesting areas of research [10, 11]. DGS with periodic or non-periodic array exhibit bandgap and slow-wave characteristics [12]. The band-rejection and slow-wave characteristics of DGS are available to realize the compact physical dimensions of circuits such as dividers, power amplifier, filters [13].

A novel compact directional coupler is proposed in this letter. It is composed of planar transmission lines with complementary split ring resonator (CSRRs) and dumbbell-like defected ground structure (DGS). The coupler is designed and measured. Promising features including reduced circuit size, low insertion loss, and high port isolation are obtained.

2. STRUCTURE AND DESIGN OF POWER DIVIDER USING USING SRRS AND DUMBBELL-LIKE DGS

The configuration of the directional coupler is shown in Fig. 2. Port 1 is the input port, and Ports 2, 3, 4 are the through, coupled and isolated ports, respectively. Stubs are introduced to the microstrip lines. CSRRs and dumbbell-like DGS are etched in the back substrate side to achieve high magnetic coupling between line and rings at resonance [14]. The equivalent circuit of the proposed DGS is depicted in Fig. 1.

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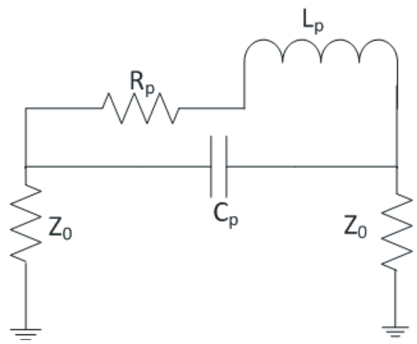

Figure 1. Equivalent circuit of the proposed DGS.

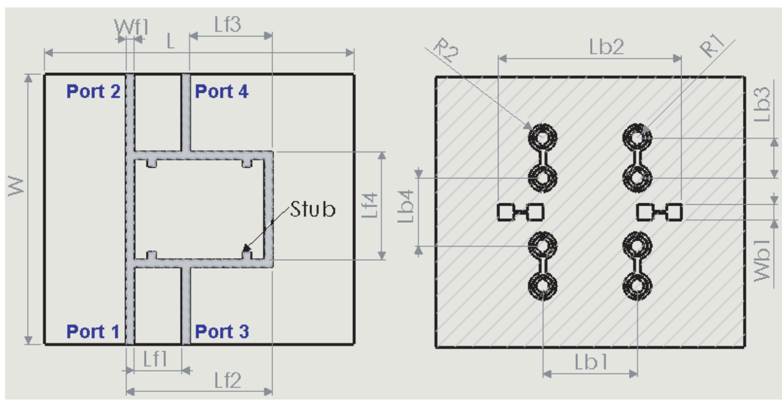

Figure 2. Topologies of the proposed directional coupler.

The directional coupler has been designed with the common PCB process on the substrate with $\varepsilon_r = 4.8$, $\tan\delta = 0.016$ and thickness $h = 1\,\text{mm}$. The parameters of the proposed divider are optimized by using commercially available software — High Frequency Structure Simulator (HFSS) based on the finite element method algorithm and a simple resonant equation. The final dimensions of the power divider are: $L = 80\,\text{mm}$, $W = 70\,\text{mm}$, $Wf1 = 2\,\text{mm}$, $Lf1 = 12.5\,\text{mm}$, $Lf2 = 38\,\text{mm}$, $Lf3 = 21.5\,\text{mm}$, $Lf4 = 28\,\text{mm}$, $R1 = 1.7\,\text{mm}$, $R2 = 3.5\,\text{mm}$, $Lb1 = 24.5\,\text{mm}$, $Lb2 = 47.5\,\text{mm}$, $Lb3 = 10.4\,\text{mm}$, $Lb4 = 17.6\,\text{mm}$, $Wb1 = 4\,\text{mm}$. The radius of the CRSSs are 1.7 and 3.5 mm respectively.

3. SIMULATED AND MEASURED RESULTS

To verify and demonstrate the proposed circuit, the power divider is designed and fabricated as shown in Fig. 3.

The simulated and measured results of the S-parameters are shown in Fig. 4, Fig. 5 and Fig. 6. The simulation and measurement for the introduced coupler are generally in good agreement. As expected, the return losses of all the ports are less than $-10\,\text{dB}$ across the designed 1.2 to 1.5 GHz frequency range.

From the measured and simulated return losses as shown in Fig. 4, the coupler provides good return loss in input port as well as in output ports. Both the measured and simulated return losses are better than $-13.5\,\text{dB}$. Therefore, the designed divider is well matched to the input and output ports. Fig. 5 indicates that the input signal is almost equally divided and transmitted to output ports 2 and 3 with insertion less than 3.5 dB across the whole designed frequency band. The isolation between two outports is higher than 20 dB as shown in Fig. 6.

The width of the microstrip line is $Wf1 = 2\,\text{mm}$. The dielectric constant (ε_r) and thickness (h) of

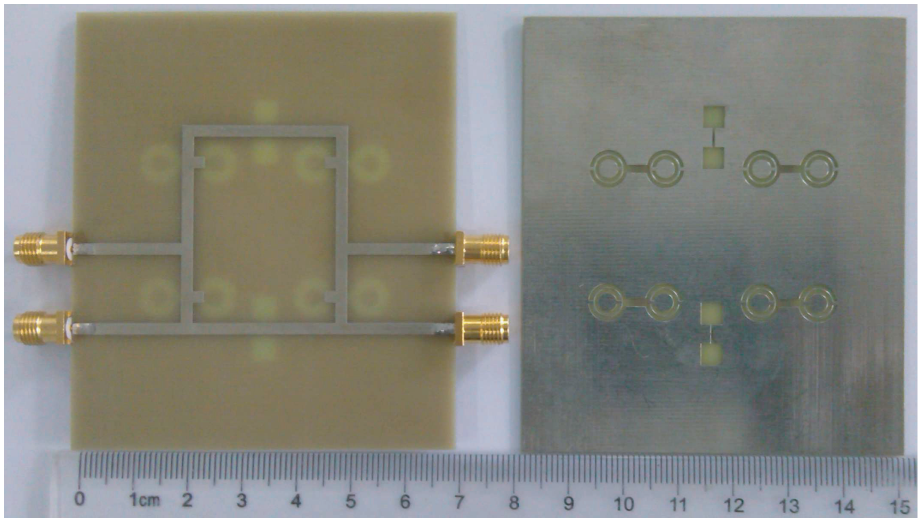

Figure 3. Geometry of the proposed divider.

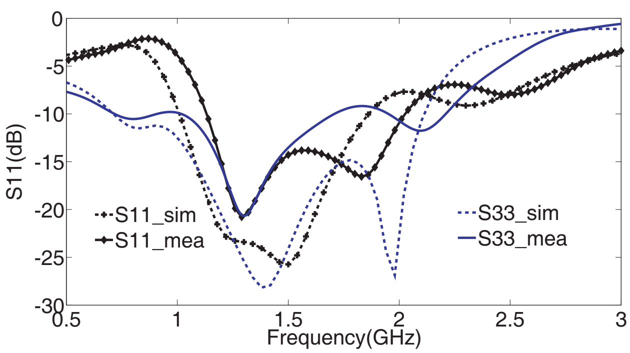

Figure 4. Simulated and measured return losses.

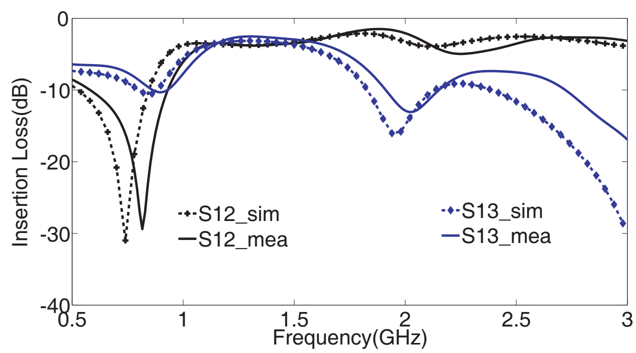

Figure 5. Simulated and measured insertion losses.

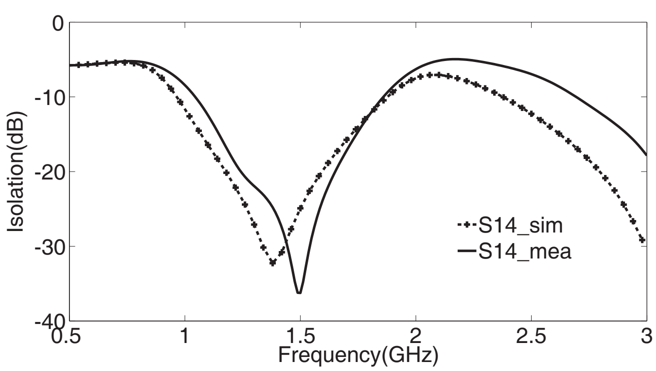

Figure 6. Simulated and measured port isolations.

the substrate are 4.8 mm and 1 mm, respectively. The effective dielectric constant can be get by:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{Wf1}\right)^{-\frac{1}{2}} \tag{1}$$

The effective wavelength λ_{re} can be obtained by:

$$\lambda_{re} = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} \tag{2}$$

where λ_0 is free space wavelength. The effective wavelength $\lambda_{re} = 116.8\,\text{mm}$. For traditional directional coupler, the distance between port 3 and port 4 is $\frac{3}{4} \times \lambda_{re}$, which is 87.6 mm, while it is just 71.0 mm ($Lf3{\times}2 + Lf4$) for the proposed direction coupler. Compared to traditional directional coupler, the length is reduced about 18.9%.

4. CONCLUSION

A novel directional coupler operating at L-band is designed, fabricated and tested. The circuit size is compact by using a split ring resonator and dumbbell-like defected ground structure. The insertion loss is less than 3.5 dB over the entire band of interest. The return loss is better than −13.5 dB with port isolation higher than 20 dB. Attractive features including miniaturized size and planar form make the coupler easily integrated in microwave and millimeter-wave circuits.

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