A Miniaturized Planar Crossover Using Dual Transmission Lines

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Abstract—This paper presents a miniaturized four-port crossover consisting two cascaded branch-line couplers implemented by dual transmission lines. A dual transmission line is composed of two parallel-connected transmission lines with high impedance and different electrical lengths. This design has the advantage of circuit layout flexibility and size reduction. The electrical size is 21% reduced comparing with the size of a crossover utilized with two cascaded branch-line couplers.

I. INTRODUCTION

A crossover is one of the fundamental components in microwave circuits design and can be applied in a Butler matrix for a switched-beam antenna array [1]. For cost reduction, fully planar crossovers have been developed for years [2]-[4]. In [2], microstrip and stripline crossovers composed of two cascaded branch-line hybrids were reported. [3] presented a compact symmetric four-port crossover using a ring and two inner orthogonal sections connecting the diagonal ports. A symmetric four-port microstrip crossover with double-ring structure was presented in [4].

In this paper, a miniaturized microstrip crossover utilizing dual transmission lines operating at 2.5 GHz is presented. The proposed circuit is based on the design method presented in [5] and using the method reported in [6][7] for miniaturization.

II. DESIGN METHODOLOGY

The circuit schematic of the proposed crossover using dual transmission lines is shown in Fig. 1(a). It is designed based on the circuit topology given in Fig. 1(b), which is implemented by two cascaded conventional branch-line couplers with all ports matched [2]. Herein, that two conventional branch-line couplers can obtain a crossover have been validated in [5].

The electric circuit layout is shown in Fig. 2. A section of transmission line and its equivalent dual transmission line are depicted. In order to miniaturize the size of circuit, dual transmission line structures mentioned in [7] are applied to replace the transmission lines in branch-line couplers as plotted in Fig. 1(b). According to Fig. 2, which has been presented in [7], the design formula of a dual transmission line can be expressed as

$$\cos \theta_0 = \frac{\sin(\theta_{n1} + \theta_{n2})}{\sin \theta_{n1} + \sin \theta_{n2}}, \quad (1)$$

$$Z_0 \sin \theta_0 = Z_n \frac{\sin \theta_{n1} \sin \theta_{n2}}{\sin \theta_{n1} + \sin \theta_{n2}}, \quad (2)$$

where $Z_0$ and $\theta_0$ are the impedance and electrical length of transmission line, respectively. $Z_n$, $\theta_{n1}$ and $\theta_{n2}$ are the impedance and electrical lengths of dual transmission line. Based on (1), for $\theta_0 = 90^\circ$, $\theta_{n1}$ and $\theta_{n2}$ can be chosen to satisfy $\theta_{n1} < 90^\circ < \theta_{n2}$ and $\theta_{n1} + \theta_{n2} = 180^\circ$. The electrical lengths of $\theta_{n1}$ and $\theta_{n2}$ can be found. By substituting $\theta_0 = 90^\circ$, $Z_0 = 50 \Omega$, $\theta_{n1}$ and $\theta_{n2}$ into (2), $Z_n$ can be determined. Moreover, in order to obtain a symmetric structure, the transmission line with impedance of $Z_0/2$ will be transferred to three transmission lines. One of them is with impedance of $Z_3$, and electrical length of $\theta_{n1}$. The other two are with impedance of $2Z_3$ and electrical length of $\theta_{n2}$.

III. IMPLEMENTATION

The proposed crossover designed to operate at 2.5 GHz. This circuit was implemented on Rogers RO4003C substrate with a
dielectric constant of 3.55, thickness of 0.508 mm and a loss tangent of 0.0027. Circuit parameters of the proposed crossover are listed in Table I. Fig.3 shows the photograph of proposed crossover with an area of 23.7 mm x 26.65 mm. The electrical size is 21% reduced comparing with the size of a crossover utilized with two cascaded branch-line couplers.

<table>
<thead>
<tr>
<th>n</th>
<th>Z_n</th>
<th>θ_1</th>
<th>θ_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>101.54 Ω</td>
<td>80°</td>
<td>100°</td>
</tr>
<tr>
<td>2</td>
<td>100 Ω</td>
<td>45°</td>
<td>135°</td>
</tr>
<tr>
<td>3</td>
<td>53.21 Ω</td>
<td>70°</td>
<td>110°</td>
</tr>
</tbody>
</table>

IV. SIMULATION AND MEASUREMENT

Fig. 4 shows the circuit simulation results obtained by Agilent Advanced Design System. The simulated data shows that the insertion loss is 0 dB, the return loss and the isolation at ports 2 and 4 are larger than 40 dB at the frequency of 2.5 GHz. Thus, the design method is applicable to obtain a crossover.

Figs 5-7 show the simulated and measured frequency responses of the circuit. The simulation is carried out using an electromagnetic full-wave solver, Agilent Momentum. The finite conductivity $\sigma = 5.8 \times 10^7 S/m$ of Cu was considered in the full-wave electromagnetic simulation. The S-parameter are measured by the network analyser Agilent E5071C over the frequency range of 0.5 to 4.5 GHz. The measured data shows that the centre frequency shifts to 2.46 GHz with the 3-dB fractional bandwidth of 28.9%. The frequency shift may be caused by fabrication tolerance. Fig. 5 shows the measured return loss ($|S_{11}|$) is less than 20 dB in the frequency range of 2.39 to 2.52 GHz. The measured insertion loss ($|S_{31}|$) is 0.88 dB at operating frequency. Fig. 6 shows the isolation between ports 1 and 2 is larger than 20 dB from 2.26 to 2.61 GHz. In the frequency range of 2.46 to 2.54 GHz, 20 dB isolation between ports 1 and 4 is also achieved, as depicted in Fig. 7. A crossover is hence obtained.
V. CONCLUSION

A compact crossover has been presented by two cascaded branch-line couplers and miniaturized with dual transmission lines design. The folding technique of layout can be easily applied because a dual transmission line is composed of two high impedance lines. This method is effective to reduce the size of a crossover. Good agreement between simulation and measurement has also been observed.

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REFERENCES