Design of Ku-band High Directivity Directional Coupler

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ABSTRACT

This paper introduces a method to improve the directivity of directional coupler. Adding open-stub to each section of the parallel coupling line. The open-stub is equivalent to a capacitance element to compensate the discontinuity of two adjacent coupled line junction. The simulation results show that this method can effectively improve the directivity of stripline directional coupler. In this paper, a Ku-band stripline directional coupler is designed, the directivity value of the directional coupler is -17dB without open-stubs. However, the directivity of the directional coupler improves 13dB with open-stubs.

KEYWORDS

High Directivity, Directional Coupler, Open-Stubs, Equivalent Capacitance.

INTRODUCTION

Directional coupler is widely used. In vector network analyzer, directional coupler is used to measure traveling wave and reflected wave. In the balanced amplifier, the directional coupler can significantly improve the voltage standing-
wave ratio (VSWR) of the amplifier. In order to adapt to the development trend of miniaturization and integration of microwave devices, microstrip directional coupler and stripline directional coupler become the key research object. However, microstrip directional couplers suffer from poor directivity due to the difference in the phase velocities of even and odd modes on coupled microstrip lines [1]. This leads to the directivity of microstrip directional coupler is not as good as that of stripline directional coupler.

When a coupler is used as a reflectometer or after a transmitter to check the integrity of its antenna connection, the sensitivity and accuracy of measurement are limited to the directivity parameter of the employed coupler [2]. It’s difficult to accurately measure a reflected power without a high directivity [3]. So, it is of great significance to study directional couplers with high directivity.

Figure 1 shows the schematic diagram of the edge-coupled stripline directional coupler. Due to the discontinuity of the adjacent coupled line junction, a parasitic inductance will be generated, which will lead to the deterioration of the directivity.

In order to compensate for the impedance mismatch caused by this discontinuity, we can add open-stub to each section of the parallel coupling line, the open-stub is equivalent to a capacitor element, this enables the impedance matching to improve the directivity of the directional coupler.

Figure 1. Schematic diagram of the edge-coupled stripline directional coupler.

**DESIGN OF COUPLER**

The aim of this paper is to improve the directivity parameter of a 14.25-15.75 GHz stripline directional coupler with 20dB coupling coefficient and a ripple equal to 0.3 dB. All parallel-coupled lines, which are supported by any TEM, have the
even and odd mode property [4]. The even and odd mode impedance satisfies the relationship:

\[ Z_{0o}Z_{0e} = Z_0^2 \]  

Where \( Z_0 \) (50Ω) means the characteristic impedance, \( Z_{0e} \) and \( Z_{0o} \) mean the even impedance and odd impedance, respectively. The odd mode capacitance \( C_o \) and even mode capacitance \( C_e \) are obtained by using the odd-even mode analysis method, and then the odd and even mode characteristic impedance can be obtained. Here we omit the complex computational process, give the results directly:

\[ \begin{align*}
Z_{0e1} &= 58.18\Omega, \\
Z_{0e2} &= 53.665\Omega, \\
Z_{0e3} &= 51.18\Omega, \\
Z_{0o1} &= 42.97\Omega, \\
Z_{0o2} &= 46.585\Omega, \\
Z_{0o3} &= 48.845\Omega.
\end{align*} \]

Figure 2 shows the schematic diagram of single parallel-coupled stripline, where \( S \) means the distance between parallel coupling lines, \( W \) and \( L \) mean the width and length of the coupling line, respectively. Next, use the LineCalc tool in ADS to calculate the specific dimensions of each parallel-coupling line. The plate of the coupler is selected as Rodgers 5880, the dielectric constant is 2.2, the loss tangent angle is 0.0009, the thickness is 60mil, and the thickness of copper is 1oz. The calculated results of LineCalc are

\[ \begin{align*}
S_1 &= 0.34\text{mm}, \\
S_2 &= 0.69\text{mm}, \\
S_3 &= 1.23, \\
W_1 &= W_2 = W_3 = 1.2\text{mm}, \\
L_1 &= L_2 = L_3 = 3.37\text{mm}.
\end{align*} \]
Figure 3 shows the coupler 3D model established in the electromagnetic simulation software HFSS.

![3D model of conventional stripline directional coupler](image)

**Figure 3.** The 3D model of conventional stripline directional coupler.

**SIMULATION RESULTS AND DISCUSSION**

Figure 4 shows the simulation results of conventional stripline directional coupler. The simulation results show that the coupling coefficient is 20dB, the worst directivity is 17dB in the whole band, at the center frequency of 15GHz, the directivity reached a maximum of 35dB.

![Simulation results](image)

**Figure 4.** The simulation results of conventional stripline coupler.

In many application scenarios, the directivity of the above simulation results is not enough to meet the application requirements. So, we need to improve the directivity of the stripline coupler. Figure 5 shows the 3D model of the stripline coupler with open-stubs. These open-stubs can compensate for discontinuities between adjacent coupling lines, and thus improve the directivity of stripline directional coupler.
Figure 5. The 3D model of stripline directional coupler with open-stubs.

Figure 6 shows the simulation results of the stripline directional coupler with open-stubs. The simulation results show that the coupling coefficient is also 20dB. It is important to note that the directionality is improved by about 13 dB. The directionality is greater than 30dB over the entire frequency band, greater than 40dB in the frequency range of 14.8-15.2GHz, and the directivity reached a maximum of 51dB at the center frequency of 15GHz. This result can meet the requirements of most applications for directional couplers.

Figure 6. The simulation results of the stripline directional coupler with open-stubs.

CONCLUSION

By comparing the above two simulation results of the stripline directional coupler, we can draw the conclusion that adding open-stubs to the parallel coupling lines can improve the directivity of the stripline directional coupler effectively. This method can be applied to any edge-coupled directional coupler.
A directivity greater than 40dB was obtained over a bandwidth of 400MHz, and the maximum value of directivity reached 51dB.

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