**Broadband Directional Coupler with High Isolation**

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**Abstract.** A novel wideband microstrip directional coupler operating at 1 to 5 GHz with high isolation is presented in this paper. Parallel coupling lines replace the traditional coupling transmission lines, providing broadband characteristics. The rectangular defected ground structure (DGS) on the RF ground on the back increases the isolation. The coupler was designed using 3D electromagnetic simulations. FR4-type dielectric substrate has been used due to its low cost. Simulation results prove that the proposed directional coupler provides an isolation of at least 20 dB on the full frequency band from 1 to 5 GHz, and reaches 66 dB at 2.89 GHz. The coupling degree is about 12 dB. Moreover, the proposed design can also achieve wide operating bandwidth (approximately 139% fractional bandwidth).

1. **Introduction**

The directional coupler is one of the important components in the radio frequency front-end system. It is widely used in power detection circuits and can perform power distribution and power synthesis in a wide frequency range. Its main function is to monitor and measure the microwave power of a certain transmission direction. With the development of microwave communication systems, directional couplers with wide bandwidth and high isolation are more and more popular.

Microstrip line-based directional couplers have the advantages of small size, light weight, simple manufacturing and easy integration, and are widely used in microwave/millimeter wave circuit systems. However, the microstrip line has quasi-TEM characteristics, and the phase velocities of the odd and even modes are not equal, resulting in low isolation.

Therefore, there have always been researches trying different methods to improve the directional coupler to improve its bandwidth and isolation. As to how to increase the bandwidth, the defected ground structure (DGS) usually exerts a pain, which enlarges the bandwidth of the coupler by affecting the characteristic impedance of the microstrip line by the different width and shape of the slot[1-5]. In addition, parallel coupling lines are often used in directional couplers to expand the bandwidth[5-7]. Branch-line directional couplers are commonly used to increase the number of branch lines to broaden the bandwidth[8-10]. As for improving isolation, DGS can also improve isolation[4,5]. For the unequal phase velocities of the odd and even modes of the microstrip line, some methods have been proposed, mainly adding compensation capacitors and inductors. The phase velocities of the even and odd modes after compensation are almost equal, which improves the isolation of the directional coupler[11-14].

In this paper, a novel wideband microstrip directional coupler operating at 1 to 5 GHz with high isolation is presented. This design is a symmetrical structure. It achieves good performance using two new technologies, which are multiple narrow parallel coupling lines and the DGS on the RF ground.
below the parallel coupling lines to expand bandwidth and improve isolation. The proposed directional coupler has an isolation higher than 20 dB through the proposed band.

2. Design and analysis of the coupler

A 1-5 GHz directional coupler having an isolation of at least 20 dB has been designed. The design is based on the structure of Figure 1 below. After theoretical research and preliminary experiments, it is observed that multiple parallel coupling lines and the DGS on the RF ground as shown in figure 1 give a preliminary result. Electromagnetic energy from the primary microstrip line is collected by these parallel coupling lines.

Here $s$ is the distance between the upper and lower parts of the parallel coupling lines. $d$ is the distance of the parallel coupling lines from the left edge of the port. $l$ and $w$ are the length and width of the parallel coupling lines, respectively. $h$ is the distance between each parallel coupled line. $m$ and $n$ are the length and width of the rectangular DGS, respectively.

![Figure 1](image)

On the basis of the structure in figure 1, a parametric study has been performed to achieve a good coupler performance. At this stage, the number of single-sided parallel coupling lines, the distance $h$ between each parallel coupled line, and the size of the rectangular DGS on the RF ground are varied to achieve better results.

2.1. The number of single-sided parallel coupling lines

We first optimized the number of single-sided parallel coupling lines. The result of isolation ($S_{13}$) is shown in figure 2 below.

It can be seen from figure 2 that when there is only one coupling line, the isolation of the coupling is less than 20 dB. As the number of parallel coupling lines increases, so does the isolation. However, 2 and 4 parallel coupled lines cannot guarantee a relatively flat isolation curve, and when there are 4 parallel coupling lines, the isolation is not below 20 dB in the whole frequency band. But the 3 parallel coupled lines can not only guarantee this, but also produce a deep notch at approximately the center frequency, providing a high degree of isolation. Therefore, the number of single-sided parallel coupling lines should be 3.
2.2. The distance $h$ between each parallel coupled line

Next what we optimized is the distance $h$ between each parallel coupled line. The result of isolation ($S_{13}$) is shown in figure 3 below.

Figure 2. Effect of the number of the parallel coupling lines on one side over the isolation performance of the coupler.

Figure 3. Effect of the distance $h$ between each parallel coupled line over the isolation performance of the coupler.
It can be seen from figure 3 that when $h=0.2$ mm or $h=1.1$ mm, the isolation is not below 20 dB in the whole frequency band. And when $h=0.2$ mm or $h=1.1$ mm, the curve of $S_{13}$ is not flat, and there is no notch near the center frequency. Only when $h=0.5$ mm, the curve of $S_{13}$ is not only relatively flat, but also has obvious notch near the center frequency, and the isolation performance is the best among them. Therefore, the distance $h$ between each parallel coupled line is selected as 0.5 mm for the present design.

2.3. The size of the rectangular DGS on the RF ground

Finally, we optimized the size of the rectangular DGS on the RF ground. Here, we mainly choose to optimize the width $n$ of the rectangle DGS. Because the length $m$ of the rectangle DGS has little effect on the result. The result of isolation ($S_{13}$) is shown in figure 4 below.

![Figure 4. Effect of the width $n$ of the rectangle DGS on the RF ground over the isolation performance of the coupler.](image)

It can be seen from figure 4 that the isolation performance is poor when $n=2$ mm, which is obviously inferior to the others. When $n=5$ mm, although the result is slightly better, there is no obvious notch near the center frequency. And when $n=3$ mm and $n=4$ mm, the two $S_{13}$ curves have obvious notches, and both have good isolation. But in comparison, the notch generated when $n=4$ mm is deeper than when $n=3$ mm, the isolation performance is better, and it is closer to the center frequency. Therefore, we set the width $n$ of the rectangular DGS to 4 mm.

3. Simulation and results

Through above optimization, we get the final dimensions of proposed directional coupler: $d=19$ mm, $l=12$ mm, $s=0.5$ mm, $w=0.1$ mm, $h=0.5$ mm, $m=24$ mm, $n=4$ mm. And there are 3 parallel coupling lines on each side. This paper uses ANSOFT electromagnetic simulation software HFSS 15.0 to simulate the directional coupler. The material of the dielectric substrate is FR4, the relative dielectric constant is 4.4, and the dielectric thickness is 1.524 mm.

The simulation results of proposed directional coupler are shown in figure 5 below. It can be seen from figure 5 that the proposed directional coupler provides a relatively flat isolation of at least 20 dB on the full frequency band from 1 to 5 GHz, and reaches 66 dB at 2.89 GHz. The coupling degree is
about 12 dB. The return loss is below 15 dB. Moreover, the proposed design can also achieve wide operating bandwidth, approximately 139% fractional bandwidth.

![Figure 5. Simulation results of proposed directional coupler.](image)

The comparison between the work of this paper and other literatures is shown in Table 1 below. As can be seen from Table 1, some designs have higher isolation, but the fractional bandwidth is very narrow. Some couplers have relatively wide fractional bandwidth, but the isolation is not high enough. In comparison, the coupler designed in this paper has relatively high isolation and relatively wide fractional bandwidth.

| Isolation (dB) | Fractional bandwidth |
|---------------|----------------------|
| This work     | -66                  | 139%                 |
| [3]           | -49.8                | 2%                   |
| [5]           | -45                  | 100%                 |
| [6]           | -46                  | 55%                  |
| [8]           | -107.9               | 4.3%                 |
| [9]           | -40/-35              | 67%/40%              |

### 4. Conclusion

A novel wideband microstrip directional coupler operating at 1 to 5 GHz with high isolation is presented in this paper. Two novel techniques have been implemented in the design: multiple narrow parallel coupling lines and the DGS on the RF ground below the parallel coupling lines. Simulation results show that the design has good performance. The proposed coupler provides a relatively flat isolation of at least 20 dB on the full frequency band and wide operating bandwidth, approximately 139% fractional bandwidth.
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