A Design of Wideband Microstrip-to-Microstrip Vertical Transition for RF Circuits

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Abstract. With the miniaturization of RF circuits, the transmission of signals in different layers becomes important. How to realize the vertical transition structure with wide transmission band and low loss has become the focus of research. In this paper, we proposed a broadband vertical transition structure design based on cavity coupling. This model achieves broadband coupling between the upper and lower microstrips by adding parabolic patches, which improves the model transmission bandwidth. The simulation results show that the optimized model has ultra-wideband transmission characteristic, the 1dB bandwidth is 3.32 GHz-10.42 GHz and the fractional bandwidth is more than 103%. What’s more, the thick ground layer of the model improves the heat dissipation performance. Therefore, this structure is very suitable for high-speed and high-density RF circuits.

1. Introduction

With the improvement of signal transmission rate and the miniaturization of devices, multilayer integrated circuits are widely used. And in multilayer integrated circuits, microstrip-microstrip vertical transition structures are essential. One of the methods to achieve vertical transition is based on via [1]. However, this method will introduce parasitic effect at high frequencies, which will damage the signal transmission. Besides, the fabrication can be difficult. Slot-coupled is the second way to achieve this goal [2-4]. This kind of vertical transition structure based on this method has a wide bandwidth but poor thermal performance. At the same time, the thickness of the ground plane of their model was assumed to be infinitesimally thin, which cannot be realized in reality. Another way is based on cavity-coupled. Cavity-coupled has lots of advantages, such as low loss, wide transmission band and good heat dissipation performance [5]. Most of previous studies focus on the design of cavity [5-6], however, the model performance can also improve by adding patches.

In this paper, a novel microstrip-microstrip vertical transition structure based on cavity-coupled is proposed. The coupling between two different layers is enhanced by adding parabolic patches. The optimized model not only has the advantages of traditional cavity coupling structure, but also further reduces the insertion loss and improves the transmission bandwidth. Through the simulation, we get that the 1dB bandwidth of the model is 3.32-10.42GHz. The minimum insertion loss in the transmission band is 0.229dB and the fractional bandwidth is more than 103%.
2. Transition Circuit Design

2.1. Design of the transition structure

The layout of the proposed transition model based on cavity-coupled is shown in Figure 1. The model consists of upper and lower microstrips, two parabolic patches, a thick ground plane and a metallic cavity. The material of the two dielectric substrates is Rogers RO4350, the thickness is 0.5 mm, the relative permittivity is 3.66. The width of the microstrips is 1.1 mm, so the characteristic impedance of microstrips is $50 \, \Omega$. In addition, two parabolic patches are opposite to each other through a metal cavity at the ends of the two microstrips in different layers respectively. In this way, the coupling of upper and lower signal is enhanced.

![Figure 1. Schematic diagram of the designed model](image1)

In this design, we consider the thickness of the common ground plane. An electrically thick ground plane can be used as a radiator for on-board active components. It can also provide isolation between different circuit layers or modules [5]. If the ground plane thickness is too large, it will deteriorate the coupling of upper and lower signal. In contrast, if the thickness is too small, it will make the heat dissipation performance of the model worse, and make the fabrication difficult as well. In consideration, we set the thickness of the common ground plane as 0.1 mm. The radius of the cylindrical metal cavity $R_{cav}$ is set to 3.5 mm, and the resonant frequency of the cavity is 39.2 GHz. The purpose of this design is to make the resonant frequency of the cavity much higher than the transmission frequency, so that it can work in non-resonant mode, to achieve a wider transmission bandwidth. The metallic cavity and the common ground plane are shown in figure 2.

![Figure 2. Layout of the metallic cavity and the common ground plane](image2)
2.2. Patches design based on parabolic shape
We add two patches at the end of the microstrips to achieve the strong coupling of the upper and lower signal. In size selection, according to the transmission line theory, the length of the patches should be 1/4 central wavelength of the operation to ensure the best transmission performance. In this paper, the patches are designed to be 7 mm in length. In addition, when the shape of the patch resembles a tapered coupled structure, an almost constant coupling value can be obtained in wider frequency band, this feature is helpful to realize the broadband transmission of the model. In this proposed model, we set the patch as a combination of two parabolas to achieve this feature, as shown in figure 3.

The quadratic coefficient of curve 1 is set as $a$, and the quadratic coefficient of curve 2 is set as $-a$. Adjusting the value of $a$ is to adjust the width of the patches. If the width is too small, the strong coupling between the upper and lower signal cannot be realized. If the width is too large, the characteristic impedance of microstrips change sharply, which will increase the return loss of the model, and damage the transmission performance. Therefore, the value of quadratic coefficient of parabola is a critical parameter for the proposed model.

Figure 3. Layout of the parabolic patch

In order to select the best parameters, we obtain the S parameters of this model at the frequency of 1-16 GHz. By changing the absolute value of the quadratic coefficient of the curves, the best performance of this model is obtained. The results are shown in table I.

| Value of the quadratic coefficient | Minimum insertion loss (dB) | 1dB bandwidth (GHz) |
|-----------------------------------|-----------------------------|---------------------|
| 0                                 | 0.264                       | 3.5-5.1             |
| 0.12                              | 0.224                       | 3.4-10.1            |
| 0.15                              | 0.223                       | 3.3-10.4            |
| 0.20                              | 0.283                       | 3.2-9.5             |
| 0.25                              | 0.278                       | 3.8-7.5             |

3. Result and Discussion
The results make known that under this current transmission scenario, when the parabolic quadratic coefficient $a$ is 0.15, the model transmission performance is best. On this premise, the minimum insertion loss of this model is 0.223 dB at 4.33 GHz, the 1dB bandwidth is 3.32-10.42 GHz. In the transmission band, the return loss of this model is better than 10dB. It shows that the model we designed has the advantages of low loss and wide transmission band. The S-parameter simulation results are shown in figure 4.
Figure 4. $S_{11}$ and $S_{21}$ of the proposed model

In order to verify the performance of the model by adding patches, we compare the transmission performance of the optimized model with that of the model without patches. Besides, to judge whether the model has ultra-wideband characteristic, the fractional bandwidth is also a critical factor. In this work, the transmission bandwidth of the proposed model is 3.32 GHz-10.42 GHz. So, the fractional bandwidth of the proposed model is 103.3%. The simulation results show that the proposed model has ultra-wideband transmission performance.

Figure 5. Comparison of model transmission coefficients

4. Conclusion
In this paper, a microstrip-microstrip vertical transition structure based on cavity-coupled is designed. This vertical signal transition structure with high bandwidth and low loss provides a solution for signal transition at different layers of RF circuits. This shows that this work is meaningful and necessary.

By adding parabolic patches at the end of the microstrips, the coupling of the upper and lower signals is enhanced. When the absolute value of parabolic quadratic coefficient $a$ is 0.15, the model can achieve the best performance. The return loss of this optimized model is better than 10dB. A minimum insertion loss of 0.223 dB is obtained at 4.33 GHz. The 1 dB bandwidth of the proposed model is 3.32-10.42 GHz, and the fractional bandwidth of the proposed model is 103.3%. At the same time, the thick ground plane provides good heat dissipation performance, which can be well used for high frequency microwave circuits.
In the future work, the sensitivity of the proposed structure will be studied to prove that the structure is robust and its performance will not be excessively damaged by the dimensional error during the fabrication processes.

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