Design of a Novel Broadband Microstrip Line-Suspended Microstrip Line Transition Circuit

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Abstract. Based on the application requirements of the suspended microstrip circuit, a novel broadband microstrip line-suspended microstrip line transition circuit is designed in this paper. The transition structure uses "V-grooved" ground structure to realize the transition from microstrip line to suspended microstrip line in the direction of electric field, and uses gradient signal line for impedance matching to expand the bandwidth. The final simulation results show that the echo loss of the structure is better than 15 dB and the insertion loss is less than 0.165 dB in the frequency range of 0-40 GHz, and the sensitivity of circuit performance to circuit size is low. This design combines the ultra-low loss suspension line with the most commonly used microstrip line circuit, and has the advantages of broadband, low insertion loss, easy processing and compact structure. It improves the application scope of the suspension microstrip circuit and can be better integrated with other circuits or systems.

1. Introduction

With the rapid development of millimeter wave technology, the demand for various millimeter wave integrated circuits is increasing. Microstrip line has become one of the most widely used planar transmission lines in millimeter-wave hybrid integrated circuits, monolithic integrated circuits and multi-chip interconnection circuits due to its advantages of easy processing and integration[1]. However, with the increase of working frequency, the loss and dispersion of microstrip line become more and more obvious, which limits its application range[2]. Suspended microstrip line is more suitable for high frequency applications than microstrip line because of its higher Q value and lower loss. At present, suspended microstrip line is widely used in passive and active circuits such as frequency multipliers, mixers, filters, couplers. It is a widely used transmission line structure in various circuits and systems design[3].

One of the important contents of millimeter wave and submillimeter wave technology research is the conversion of electromagnetic signals between different media. Because microstrip line is still the most commonly used transmission structure of monolithic integrated circuits and active circuits, realizing a good transition from microstrip line to suspended microstrip line, the suspended microstrip circuit can be integrated with monolithic integrated circuit or active circuit for application[4]. This improves the integration of the circuit system and the application range of the suspended microstrip circuit. It also adapts to the conversion requirements between different transmission systems. Therefore, it is of great significance and value to develop and design a broadband, low loss and easy-to-process transition circuit from microstrip line to suspended microstrip line.
In this paper, a broadband microstrip-suspended microstrip line transition circuit with a central frequency of 18 GHz is designed. The transition structure uses "V-grooved" ground structure to realize the transition from microstrip line to suspended microstrip line in the direction of electric field, and uses gradient signal line for impedance matching to expand the bandwidth. The final simulation results show that the echo loss of the structure is better than 15 dB, the insertion loss is less than 0.165 dB in the frequency range of 0-40 GHz, which meets the design and application requirements of the circuit and system.

2. Analysis of The Transitional Structure
Suspended microstrip line is evolved from stripline. The main mode of internal transmission is quasi-TEM mode. Its structure is shown in Fig. 1. It consists of upper and lower metal shells and a middle layer of dielectric substrate\[5\]. Unlike the traditional microstrip line, the upper and lower layers of the suspended microstrip line are air media, and there is no metal ground. Therefore, the electromagnetic field of the suspended microstrip line is mainly distributed in the upper and lower layers of the air cavity, and the medium effect is not very large, which is comparable to the characteristics in the air. Its equivalent dielectric constant is very low, and the dielectric loss and dispersion are very small. At the same time, due to the existence of metal cavity, its electromagnetic shielding performance is also very good. The circuit on the suspended microstrip line dielectric substrate is connected to the ground through two metal cavities on both sides, so the circuit design can be carried out on both sides of the dielectric substrate\[6\]. Compared with microstrip circuit, the design of suspended microstrip circuit is more flexible.

Fig. 1. The structure of suspended microstrip line.

The characteristic impedance of suspended microstrip line\[5\] is:

\[
Z_e = \frac{60}{\sqrt{\varepsilon_r}} \ln \left[ \frac{f(x)}{x} + \sqrt{1 + \frac{4\pi}{x}} \right]
\] (1)

In formula, \(x = \frac{w}{a+b}\), \(f(x) = 6 + (2\pi - 6)\exp\left[-\left(\frac{30.6666}{u}\right)^{0.725}\right]\).

Its equivalent dielectric constant\[5\] is:

\[
\varepsilon_e = \left(\frac{1}{\sqrt{\varepsilon_r}} - 1\right)^{-1} \left[ 1 + \frac{a}{b} \left( m - n \ln \frac{w}{b} \right) \right]
\] (2)

In formula, \(m = \left(0.8621 - 0.1251\ln \frac{a}{b}\right)^4\), \(n = \left(0.4986 - 0.1397\ln \frac{a}{b}\right)^4\).

Since the propagation mode of microstrip line is also quasi-TEM mode, it is not necessary to consider the conversion of propagation mode in the design of microstrip-suspended microstrip line transition structure as in the design of Waveguide-microstrip transition. The key point of this design is to achieve a good broadband transition from microstrip line to suspended microstrip line. By improving impedance matching and electromagnetic matching, the bandwidth of the transition structure can be effectively expanded. In addition, the discontinuity and mutation of the transition structure will cause reflection at the junction and excite high-order modes, thus increasing the echo
loss and insertion loss of the whole structure[7]. Therefore, the design of the transition structure focuses on the following factors: (1) matching of electromagnetic fields between different transmission lines; (2) matching of impedance; (3) compensation of discontinuity of the structure.

The matching of electromagnetic fields between different transmission lines is usually achieved by the design of the physical shape of the transition structure[8]. The main purpose here is to realize the transformation from the vertical downward distribution of electric fields in microstrip lines to the divergent distribution of electric fields around suspended microstrip lines. Therefore, this paper designs a "V-grooved" ground structure to realize the transition from microstrip line to suspended microstrip line in the direction of electric field. Considering the impedance matching of the transition structure and the discontinuity compensation of the structure, the gradual signal line structure is adopted to realize the transition from metal conductor of microstrip line to metal conductor of suspended microstrip line. The model of the transition structure is shown in Fig. 2.

![Fig. 2. The model of the transitional structures.](image)

### 3. Design of The Simulation Software

In the analysis of the previous section, the overall model of the microstrip-suspended microstrip transition structure has been determined. In the following section, the transition structure is modeled and simulated by three-dimensional electromagnetic simulation software. Firstly, the transition structure model is established. In this process, the dielectric substrate is Duriod 5880, the dielectric constant is 2.2, the thickness of the substrate is 0.127 mm, the width of the microstrip line is 0.375 mm (characteristic impedance is 50Ω), the width of the suspended microstrip line is 1.75 mm, and the width of the whole structure is 3 mm. In addition, the existing research results show that when the length of the transition structure is close to one fourth of the central wavelength, it is advantageous to achieve wider bandwidth[5]. In this paper, the central frequency is 18 GHz, so the length of the transition structure is 3.7 mm. At the same time, in order to keep the transmission cavity as consistent as possible with the actual production, and then more accurately simulate the transmission of radio frequency signal in the suspended microstrip line, the width of 0.1 mm is reserved outside the air cavity on both sides of the dielectric substrate[9]. Finally, the transition structure simulation model is established by three-dimensional electromagnetic simulation software as shown in Fig. 3.

![Fig. 3. The simulation model of the transition structure.](image)

In the process of the simulation design, the height of the air cavity provided by the upper and lower metal enclosures of the suspended microstrip line and transition structure is a key parameter, which has a great influence on the transition performance[7]. This is because the height of the upper and lower air cavity not only determines the frequency characteristics of the whole structure, but also affects the insertion loss, the echo loss and the frequency band range. So the next main work is to optimize the height of the air cavity.

Firstly, the transition structure is optimized at the center frequency of 18 GHz. After the simulation and optimization of the corresponding size parameters, the optimum height of the upper and lower air cavity is $h_1 = 0.43\text{mm}$, $h_2 = 0.36\text{mm}$ ($h_1$ is the height of the upper air cavity of the dielectric plate, $h_2$ is the height of the lower air cavity of the dielectric plate). According to the above parameters, the simulation results are shown in Fig. 4 and Fig. 5. This simulation results show that the insertion loss of the transition structure is less than 0.038 dB and the echo loss is more than 22.5 dB in the 16-20 GHz range.
bandwidth range. Especially at the center frequency of 18 GHz, the insertion loss is 0.014 dB and the echo loss is 41.5 dB, which verifies the feasibility of the scheme.

Fig. 4. The insertion loss of the transition structure.

Then, in order to verify the broadband characteristics of the transition structure, the simulation model of the transition structure is optimized in the whole frequency band of 0-40 GHz. After the simulation and optimization of the corresponding size parameters, the optimum height of the upper and lower air cavity is $h_1 = 0.75$ mm and $h_2 = 0.18$ mm. According to the above parameters, the simulation results are shown in Fig. 6 and Fig. 7. The simulation results show that the insertion loss of the transition structure is less than 0.165 dB and the echo loss is more than 15 dB in the whole frequency band of 0-40 GHz. The performance of the structure is excellent, which verifies the broadband characteristics of the structure.

Fig. 5. The echo loss of the transition structure.

Fig. 6. The insertion loss in the 0-40 GHz band.
Fig. 7. The echo loss in the 0-40 GHz band.

4. Tolerance Analysis of The Simulation Results

Considering that there will be some errors in the actual production and processing of the transition structure, and because of the existence of processing and assembly errors, the change of the circuit structure of 0.01mm will have a certain impact on the performance\(^9\). It is also known from the previous analysis that the height of the upper and lower air cavity is a key parameter, which has a great influence on the transition performance. Therefore, tolerance analysis is carried out for the processing and assembly errors of \(h_1\) and \(h_2\) in this paper. The results are shown in Fig. 8 and Fig. 9. Fig. 8 and Fig. 9 are the changes of echo loss in the transition structure caused by the height change in 0.01 mm of the upper and lower air cavity.

Fig. 8. The influence of \(h_1\) change on echo loss.

Fig. 9. The influence of \(h_2\) change on echo loss.
From the figure, it can be seen that the influence of processing error on the echo loss of the transition structure is not large, and the maximum impact of the fluctuation is only 1 dB compared with the original value, and the echo loss remains greater than 15 dB in most frequency ranges. Therefore, the influence is acceptable, which also shows that the performance of the transition structure is less sensitive to the size of the circuit and is easy to process.

5. Conclusion

In this paper, a novel broadband microstrip line-suspended microstrip line transition circuit is designed. The transition structure uses "V-grooved" ground structure to realize the transition from microstrip line to suspended microstrip line in the direction of electric field, and uses gradient signal line for impedance matching to expand the bandwidth. The structure is simulated and optimized by three-dimensional electromagnetic simulation software. The final simulation results show that the echo loss of the structure is better than 15 dB and the insertion loss is less than 0.165 dB in the frequency range of 0-40 GHz. Moreover, the sensitivity of circuit performance to circuit size is low and easy to process. This design combines the ultra-low loss suspension line with the most commonly used microstrip line circuit, and has the advantages of broadband, low insertion loss, easy processing and compact structure. It improves the application scope of the suspension microstrip circuit and can be better integrated with other circuits or systems.

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