A DUAL-BAND MICROSTRIP ANTENNA DESIGN AND ANALYSIS METHOD BASED ON MULTI BRANCH

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With the continuous advancement of wireless communication technology, the antenna, as a key module of the wireless system, is gradually developing in the direction of multi-function, miniaturization, and high spectrum utilization. Among them, multi-band microstrip antennas not only have the characteristics of miniaturization, high gain, and wide frequency bands of traditional microstrip antennas, but can also meet the requirements of high spectrum utilization and the needs of users in different fields. It is an important research part of 5G antenna design.

In this paper, a dual-band microstrip antenna based on the multi-stub method is designed. The antenna is composed of a symmetrical radiating stub patch, a feeder, a dielectric substrate and a metal ground. And using return loss parameters, standing wave ratio, working frequency and bandwidth as consideration indicators, through the comparison and analysis of HFSS simulation results, it is suitable for some WiMAX and 5G frequency bands. Finally, the influence of the antenna structure on the microstrip antenna is studied, and the simulation results are compared and analyzed, and the optimal size of the antenna is determined. The dual-band microstrip antenna designed in this paper based on the multi-branch method has a simple structure and good performance, which has certain reference significance for the design and research of multi-band antennas.

Key Words: *dual-band antenna, microstrip antenna, multi-branch method, antenna gain*

1. INTRODUCTION

The level of communication technology has become an indispensable hard indicator in various countries today. In a developed communication system, the antenna plays a very important role as a module for receiving signals, and it determines the quality of the signals we receive and send. So, with a reasonable structure and excellent performance of the antenna, reducing the maximum extent of the entire wireless system requirements, thereby enabling system costs down while maintaining a satisfactory performance.

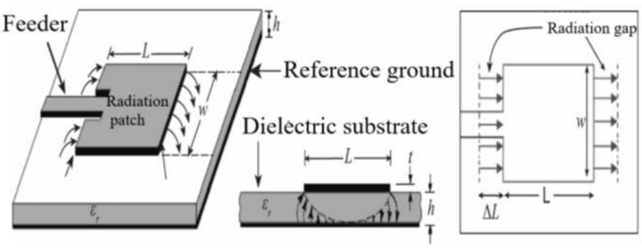
The commercialization of 5G technology in 2020 means that a new generation of communication technology has been used in our normal lives. New technologies and new standards require us to correspondingly improve the performance and various index technologies of our communication system modules. 5G not only affects the internet speed of our mobile phones, but more importantly, its integration with our traditional industries has brought people a brand-new lifestyle and experience. It can also be expected in emerging fields such as artificial intelligence and big data in the future. Therefore, the use of frequency bands should also be more scientific, which also requires our current antennas to serve various fields, such as aircraft and aerospace, satellite services, and terrestrial base stations. This article is from this point of view, research and design antennas that can work in multiple frequency bands.

2. THEORETICAL FUNDAMENTALS OF MICROSTRIP ANTENNAS

As early as 1953, G. A. Deschamps proposed the concept of microstrip antenna. A microstrip antenna is an antenna formed by etching a metal patch on a dielectric substrate containing a conductive ground plate. This article will design a dual-band microstrip antenna based on the multi-branch method, which can achieve the advantages of miniaturization and multi-band.

(1) Theory of Microstrip Antenna Radiation

The shape of the radiation patch of the microstrip antenna is generally a regular polygon. In addition, microstrip antennas are roughly divided into three categories based on structural characteristics, which are microstrip patch antennas, microstrip slot antennas, and microstrip traveling wave antennas. Taking a microstrip patch antenna as an example, as shown in **Fig.1(a)**, the radiation patch, dielectric substrate, and reference ground of the antenna can be equivalent to a microstrip transmission line, and both ends are open. The electromagnetic wave radiation is generated by the open circuit between the edge of the radiating patch and the dielectric substrate, and the electric field generated at the open end can be divided into two horizontal and vertical components. The two vertical components have opposite directions, and the two horizontal components are in the same direction. As shown in **Fig.1(b)** and **Fig.1(c)**.



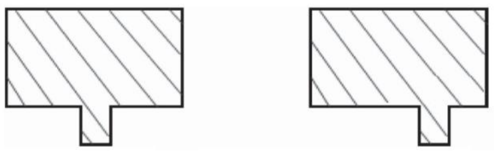
(a) Front view (b) Side view (c) Top view

Fig.1 Basic structure of microstrip patch antenna.

(2) Design method of microstrip antenna

The feeding methods of microstrip antennas include microstrip line feeding, coaxial feeding, coupling feeding and slot feeding, etc. The commonly used feeding methods are microstrip line feeding and coaxial feeding.

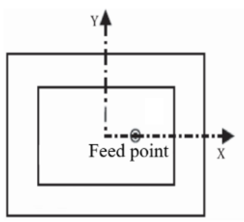
The microstrip line feed mode directly connects the microstrip transmission line and the radiating unit, and uses the microstrip transmission line for power feeding, which is also called side feed. As shown in **Fig.2**, the microstrip line feed mode of antenna reference ground is divided into center feed and eccentric feed according to the microstrip line feed position.



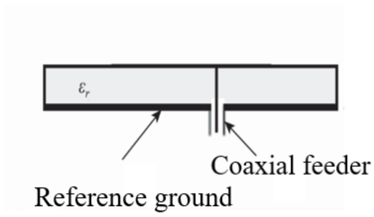
(a) Center feed (b) Eccentric feed

Fig.2 The basic structure of microstrip line feed.

The coaxial feeding method is to install a coaxial socket on the grounding plate of the dielectric substrate, and the conductor in the socket is inserted through the dielectric substrate to connect to the radiation patch, as shown in **Fig.3**.



(a) Top view



(b) Side view

Fig.3 Basic structure of coaxial feed.

To design a microstrip antenna, first calculate the size of the dielectric substrate. Assuming that the shape of the microstrip antenna is rectangular, the dielectric constant of the dielectric substrate is ε_r, the operating frequency of the antenna is f, and w is the width of the radiating element of the microstrip antenna.

$$w = \frac{c}{2f}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}} \tag{1a}$$

Among them, c is expressed as the speed of light.

In general, the length of the radiation patch of the microstrip antenna is taken as $\lambda_e / 2$, and λ_e is the wavelength of the guided wave in the medium, expressed as:

$$\lambda_e = \frac{c}{f\sqrt{\varepsilon_e}} \tag{1b}$$

Due to the edge shortening effect, the actual patch element length of the antenna is:

$$L = \frac{c}{f\sqrt{\varepsilon_e}} - 2\Delta L \tag{1c}$$

Among them, ε_e represents the effective dielectric constant, and ΔL is the equivalent radiation gap length. Its expression is as follows:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}} \tag{1d}$$

$$\Delta L = 0.412h\frac{(\varepsilon_e + 0.3)(w/h + 0.264)}{(\varepsilon_e - 0.258)(w/h + 0.8)} \tag{1e}$$

(3) Design parameters of microstrip antenna

The parameters describing the working characteristics of the antenna are called the electrical parameters of the antenna, and the electrical parameters of the antenna are mainly divided into circuit characteristic parameters and radiation characteristic parameters. The circuit characteristic parameters include input impedance, bandwidth, efficiency and matching degree, etc. Radiation characteristic parameters include pattern, gain, polarization and axial ratio, etc.

a) Input impedance

The ratio of the voltage to the current at the antenna input. The influencing factors of the input impedance of the microstrip antenna are the shape of the radiating element and the operating frequency. In general, the characteristic impedance value of the microstrip line is selected as 50.

b) Bandwidth

The antenna bandwidth is an important indicator to measure the basic performance of the antenna. It mainly measures the absolute bandwidth and the relative bandwidth. It is usually measured by the frequency band with the reflection coefficient less than -10dB or the voltage standing wave ratio less than 2.

c) Efficiency

The effective degree of the antenna in converting the input high frequency energy into radio wave energy. Its value is the ratio of the antenna radiation power and the input power. The expression is as follows:

$$\eta_A = \frac{P_{rad}}{P_{in}} \tag{1f}$$

d) Gain

Under the condition of the same input power and the same distance, the ratio of the power density of the antenna in the maximum radiation direction to the non-directional antenna in this direction. The expression of antenna gain G is as follows:

$$G = \frac{4\pi}{P_{in}} \tag{1g}$$

e) The polarization of the antenna

Refers to the electromagnetic wave direction of the radiated signal at the transmitting end of the antenna. Generally, antenna polarization can be divided into linear polarization, circular polarization and elliptical polarization.

(4) Multi-band realization method of microstrip antenna

With the increasing development of modern wireless communication systems, a single frequency band microstrip antenna cannot meet the needs of equipment. The multi-band technology of the antenna is put on the agenda, and the method to realize the multi-band has been developed. Among the more commonly used methods are multi-branch method, loading parasitic branch method, multi-slit method and reactance loading method. These methods are added to the design of the antenna, to achieve multi-band antenna characteristic.

a) Multi-branch method

The multi-branch method is one of the important methods to realize the multi-band antenna. Usually the length of the branch is taken as a quarter length of the center frequency wavelength of the microstrip antenna, and the length of the branch is changed to obtain different operating frequency bands. Therefore, a multi-band microstrip antenna can be designed by designing two or more different branch structures on a microstrip antenna at the same time. Because of the simple and easy implementation of the multi- branch method, it is widely used in the design of multi-band microstrip antennas. As the number of branches increases, due to the coupling effect between the branches, adjusting the specific parameters of one branch will affect the resonance frequency of other branches.

b) Loading parasitic branch method

The branch structure loaded on the opposite side of the feed plane on the dielectric substrate of microstrip antenna is called parasitic branch, which is called parasitic branch loading method. By loading the parasitic branches, the parasitic branches are coupled with the branches of the feed plane, and a new frequency band is generated. Because of the diversity of branch structure, easy implementation and easy adjustment, it is widely used in the fabrication of multi band microstrip antenna.

c) Multi-slit method and reactance loading method

The multi slot method is to change the current path on the surface of the radiation patch by cutting slots on the radiation patch to form a new resonant frequency band. Generally, there are many different slot types, such as L-shaped slot, F-shaped slot, U-shaped slot, E-shaped slot, ten shaped slot, rectangular slot, circular slot and irregular slot.

d) Reactance loading method

The reactance loading method is to increase the working frequency band of the antenna by adding a reactive load device to the coupled resonant circuit. It is typically accomplished by the design of the antenna equivalent circuit by modifying or adding capacitance reactance loading device by notching on the radiating patch, or. Commonly used reactance loads are: gaps, capacitors, etc. The multi-band microstrip antenna designed by the reactance loading method can effectively increase the bandwidth of the antenna and effectively improve the narrowband characteristics of the antenna.

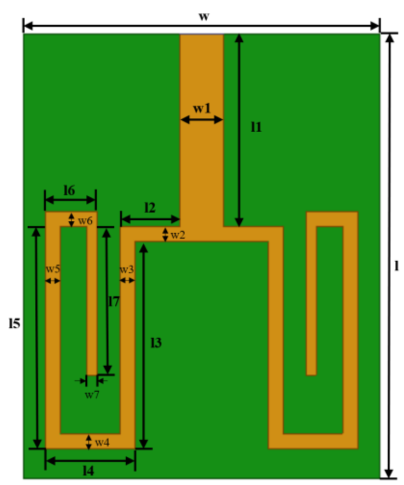
3. A DESIGN OF A DUAL-BAND MICROSTRIP ANTENNA BASED ON THE MULTI-BRANCH METHOD

As early as 1953, G. A. Deschamps proposed the concept of microstrip antenna. A microstrip antenna is an antenna formed by etching a metal patch on a dielectric substrate containing a conductive ground plate. This article will design a dual-band microstrip antenna based on the multi-branch method, which can achieve the advantages of miniaturization and multi-band.

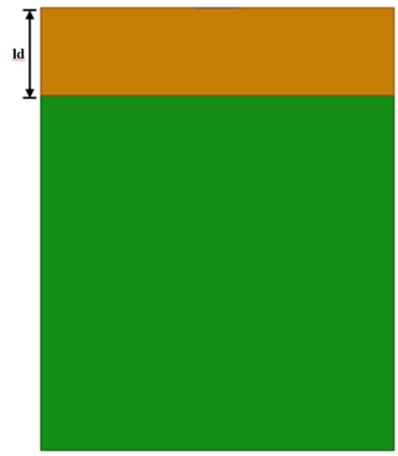
(1) Design process of multi-branch microstrip antenna

The dual-band microstrip antenna designed in this section has a multi-branch structure with a ground plane on the bottom surface of the dielectric substrate. We can get different frequency bands through the mutual coupling of individual branches. In order to get better gain, we choose symmetrical radiation patch in the design. From (1a) to (1e), we can get the approximate range of microstrip antenna size parameters, and then optimize the antenna size to get the optimal size parameters values in the table below. Each dimension parameter of antenna is shown in **Table 1** and shown in **Fig.4**.

The front view is shown in **Fig.4(a)**, and the rear view is shown in Figure **Fig.4(b)**. The antenna uses FR-4 dielectric substrate with a dielectric constant of 4.4, and its specification is 30mm*24mm*1.6mm. It can be seen from **Fig.4** that the antenna is composed of a symmetrical radiating patch, a belt feeder, a dielectric substrate and a metal ground. The antenna covers 2.90Ghz ~ 3.35Ghz and 5.15Ghz ~ 5.68Ghz bands, of which 2.90Ghz ~ 3.35Ghz band includes WiMAX part and 5.15Ghz ~ 5.68Ghz band includes 5G sub band.



(a) Front view



(b) Rear view

Fig.4 Microstrip antenna structure based on multi-branch method.

Table 1 Structural parameters of the antenna (unit: mm)

parameter	l	w	l1	w1	l2	w2	l3	w3
value	30	24	1.6	3	4	1	14	1
	l4	w4	l5	w5	l6	w6	l7	w7
	6	1	15	1	3.5	1	10	0.7
	n1	n2	n3	n4	k	ld		
	18	20	8.5	12.5	4	6		

(2) Simulation results of multi-branch microstrip antenna

Using HFSS simulation analysis, the S11 parameter curve of the microstrip antenna based on the multi-branch method is shown in **Fig.5** under the sweep frequency analysis of 2GHz~7GHz. The antenna input return loss S11 is always less than -10dB in the two frequency bands of 2.90GHz~3.35GHz and 5.15GHz~5.68GHz, and resonance points are generated at the frequencies of 3.09GHz and 5.34GHz, and the return losses are −21.71dB and -29.27dB.

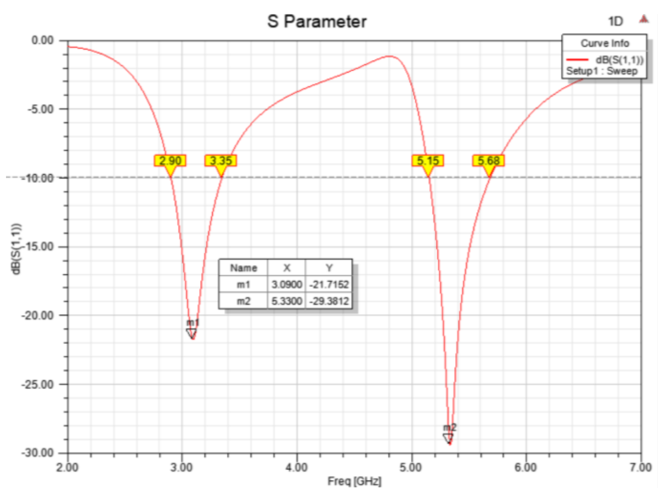


Fig.5 S11 parameter curve of microstrip antenna based on multi-branch method.

As shown in **Fig.6**, in the VSWR result of the microstrip antenna, the VSWR value is less than 2 in the frequency bands of 2.89GHz~3.36GHz and 5.14GHz~5.70GHz.

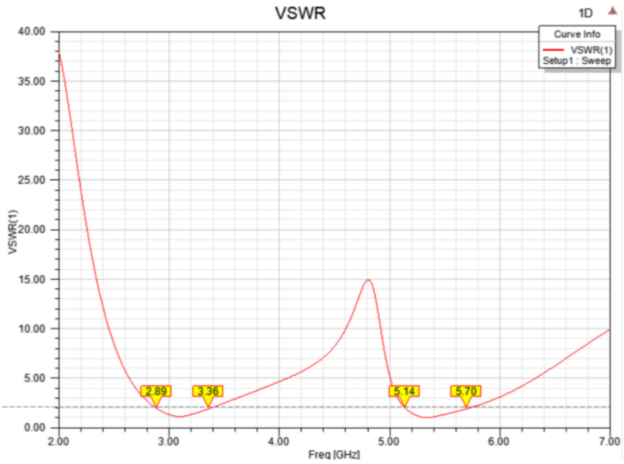
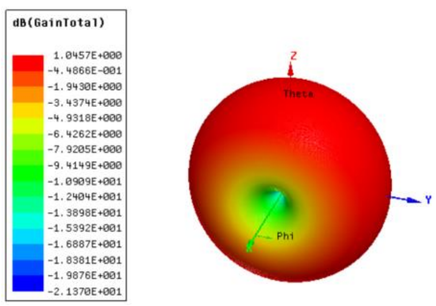
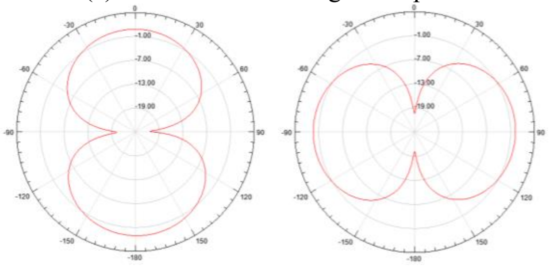


Fig.6 VSWR parameter curve of microstrip antenna based on multi-branch method.

The two-dimensional gain diagram and three-dimensional gain diagram of the microstrip antenna based on the multi-branch method are shown in **Fig.7**. Through the three-dimensional antenna gain diagram, we can know that the antenna gain is 1.05dB. The XOZ plane is defined as the E plane, and the XOY plane is defined as the H plane. The two-dimensional gain diagrams are shown in **Fig.7(b)** and **Fig.7(c)**. According to the three-dimensional gain diagram **Fig.7(a)**, the gain shape of the antenna YOZ surface is almost a circular shape, so the dual-band microstrip antenna is an omnidirectional antenna.



(a) Three-dimensional gain map



(b) E side (c) H side

Fig.7 Microstrip antenna gain diagram

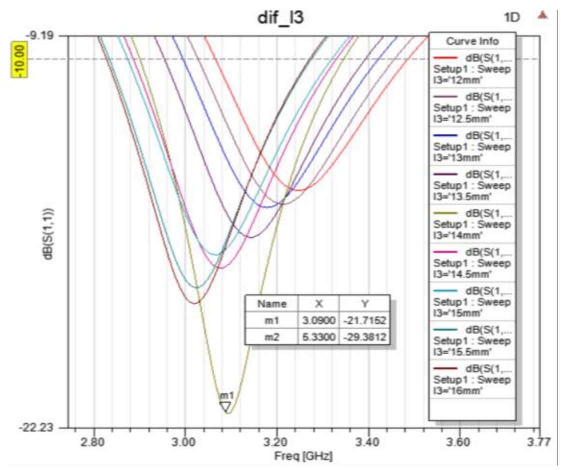
(3) Analysis of the influence of antenna structure on microstrip antenna

a) The influence of branch length l3 and l5 on microstrip antenna

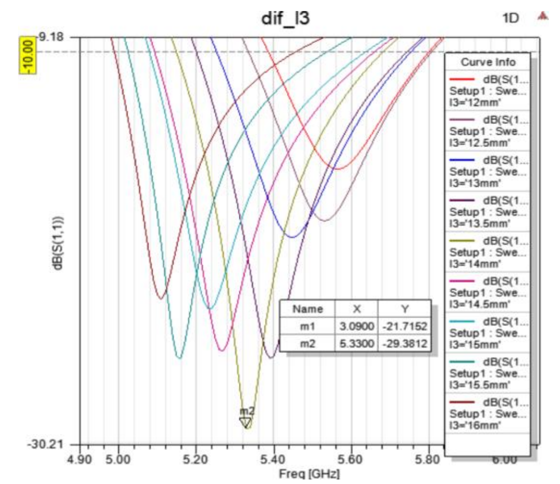
Changing the length of the branch can get different working frequency bands, changing the length of the branch l3, the length of l5 is determined unchanged. The curve of multi-branch microstrip antenna changing with S11 parameter of l5 is shown in **Fig.8**. I choose several typical values to compare in **Table 2**.

Table 2 Comparison of parameters under different l3

The value of L3 (mm)	Frequency band range less than - 10dB	
	low frequency band	high frequency band
12	3.07GHz~3.48GHz	5.39GHz~5.80GHz
14	2.90GHz~3.35GHz	5.15GHz~5.68GHz
16	2.83GHz~3.27GHz	4.99GHz~5.45GHz
	Resonance frequency / Minimum return loss	
	low frequency band	high frequency band
12	3.25GHz/-14.52dB	5.57GHz/-15.97dB
14	3.09GHz/-21.72dB	5.33GHz/-29.38dB
16	3.03GHz/-18.05dB	5.11GHz/-22.69dB



(a) low frequency band



(b) high frequency band

Fig.8 Variation curve of S11 parameter of multi-branch microstrip antenna with l3.

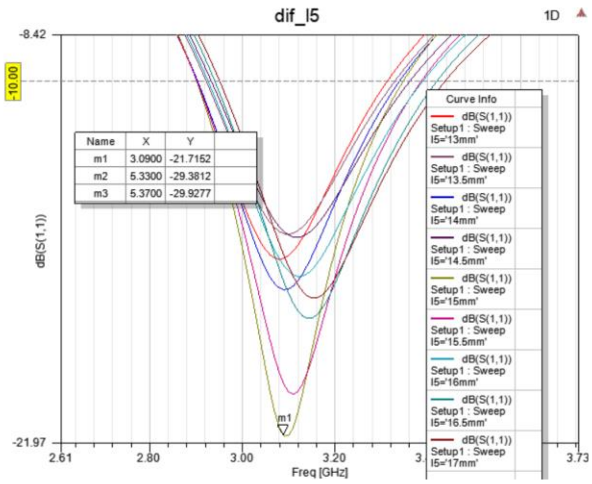
When the length of l3 varies from 12mm to 16mm and the change interval is 0.5mm, with the gradual increase of l3, the resonance points of the high and low frequency bands all move to the left, and the S parameter value gradually increases. When l3=14mm, the input return loss of the antenna reaches the minimum in the high and low frequency range. As the length increases, the S parameter value begins to decrease, and the return loss gradually increases.

The results show that when l3=16mm, the minimum frequency intersecting with -10dB and when l3=12mm, the maximum frequency intersecting with - 10dB are in the range of 2.83Ghz ~ 3.84Ghz and 4.99Ghz ~ 5.80Ghz. At this time, the return loss parameter when l3 takes different values cannot satisfy that it is always less than -10dB. When l3 is 14mm, the antenna input return loss is the smallest among the 9 cases, which are -21.72dB and -29.38dB respectively.

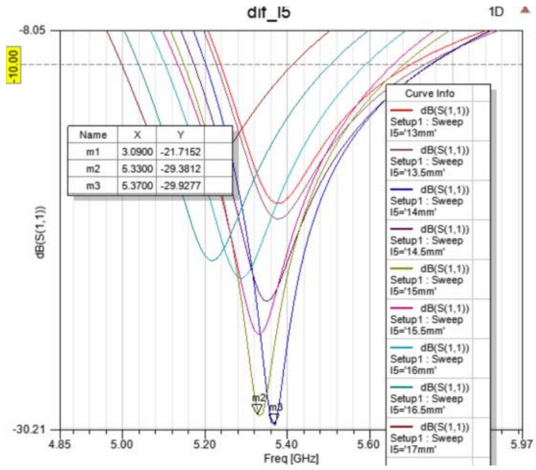
Change the length of the branch l5, and the length of l3 will remain unchanged. The change curve of the multi-branch microstrip antenna with the S11 parameter of l5 is shown in **Fig.9**. Several typical values are shown in **Table 3**.

Table 3 Comparison of parameters under different l5

The value of L5 (mm)	Frequency band range less than - 10dB	
	low frequency band	high frequency band
13	2.09GHz~3.31GHz	5.24GHz~5.69GHz
15	2.90GHz~3.35GHz	5.15GHz~5.68GHz
17	2.95GHz~3.43GHz	5.00GHz~5.41GHz
	Resonance frequency / Minimum return loss	
	low frequency band	high frequency band
13	3.08GHz/-15.85dB	5.38GHz/-17.64dB
15	3.09GHz/-21.72dB	5.33GHz/-29.38dB
17	3.16GHz/-17.14dB	5.16GHz/-17.19dB



(a) low frequency band



(b) high frequency band

Fig.9 Variation curve of S11 parameter of multi-branch microstrip antenna with l5.

When the length of l5 varies from 13mm to 17mm and the variation interval is 0.5mm, the resonance points of high and low frequency bands move to the right with the gradual increase of l5. The input return loss of the antenna reaches the minimum in the low frequency band when l5=15mm, but it is slightly less than the return loss of l5=14mm in the high frequency band. When l5=14mm, the return loss in the low frequency range is quite different from the return loss when l5=15mm.

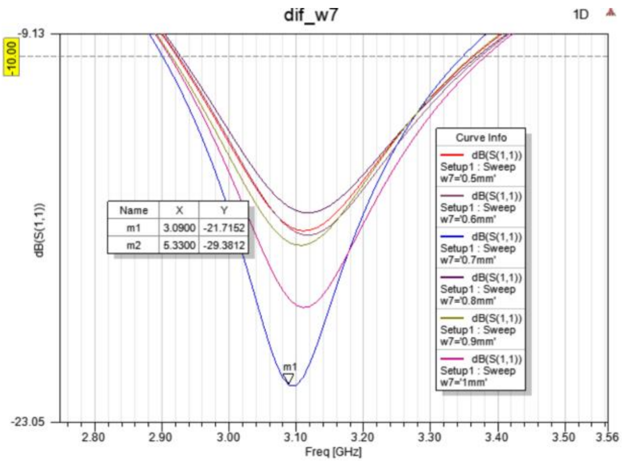
When l5 is 15mm, the antenna input return loss is -21.72dB in the 9 cases in the low frequency range. But in this case, the input return loss in the high frequency range is -29.38dB, which is slightly larger than the minimum return loss of -29.93dB when l5=14mm.

b) The influence of multi-branch structure width w7 on microstrip antenna

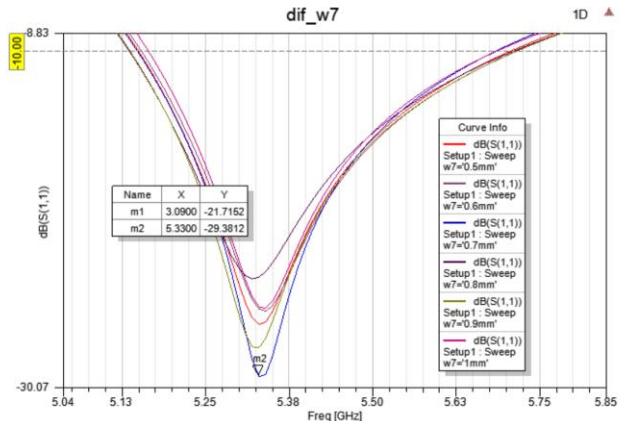
The influence curve of the multi-branch structure width w7 on the input return loss S11 parameter of the microstrip antenna is shown in **Fig.10**. Several typical values are shown in **Table 4**.

Table 4 Comparison of parameters under different w7

The value of w7 (mm)	Frequency band range less than - 10dB	
	low frequency band	high frequency band
0.5	2.92GHz~3.36GHz	5.15GHz~5.70GHz
0.7	2.90GHz~3.35GHz	5.15GHz~5.68GHz
1	2.91GHz~3.38GHz	5.17GHz~5.68GHz
	Resonance frequency / Minimum return loss	
	low frequency band	high frequency band
0.5	3.11GHz/-16.32dB	5.33GHz/-26.28dB
0.7	3.09GHz/-21.72dB	5.33GHz/-29.38dB
1	3.11GHz/-18.93dB	5.33GHz/-25.21dB



(a) low frequency band



(b) high frequency band

Fig.10 Variation curve of S11 parameter of multi-branch microstrip antenna with w7.

At this time, the variation range of width w7 is 0.5mm~1mm, and the variation interval is 0.1mm. In the low frequency range of 2.90GHz~3.38GHz, with the change of width w7, the resonance frequency of the antenna floats around 3.10GHz. When w7 is set to 0.7mm, the minimum return loss parameter of the microstrip antenna is -21.72dB. In the high frequency range from 5.14GHz to 5.71 GHz, the minimum return loss parameter of the microstrip antenna is -29.38dB when w7 is set to 0.7mm.

In this chapter, we only study the influence of branch length l3 and l5, and branch width w7 on the microstrip antenna. Under the condition of keeping other parameters of the antenna unchanged, we change the values of parameters l3, l5 and w7 one by one. Similarly, the length of other branches and branches can be changed one by one to determine the size of the antenna. Finally, the two working frequency bands of the dual-band microstrip antenna with branch coupling structure are 2.90GHz ~ 3.35GHz and 5.15GHz ~ 5.68GHz respectively.

4. CONCLUSION

In this paper, we introduce the design method of multi-band antenna, and design a dual-band microstrip antenna through the branch coupling method. Then the influence of the length and width of the microstrip antenna on the microstrip antenna is studied. Compared with the traditional single-branch structure, the antenna has the advantages of multi band and high gain. The antenna covers 2.90GHz ~ 3.35GHz and 5.15GHz ~ 5.68GHz. In these two frequency bands, the microstrip antenna has good impedance matching, ideal gain and omni-directional radiation characteristics, which can meet the traditional classic frequency band and 5G frequency band widely used at present, and meet the requirements of modern wireless system for microstrip antenna.

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