Broadband Microstrip Antenna Overview

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Abstract: Microstrip antennas are widely used in people's daily life. Microstrip antenna has the advantages of low cost, low profile, small space occupation, and high conformal capability. So the design of microstrip antennas can be encountered in daily life. Microstrip antennas include the military, aerospace, medical, and so on. Microstrip antenna has a wide research space. The three microstrip antennas, U-shaped open slit laminated microstrip antenna, dual frequency circularly polarized laminated microstrip antenna, and non-radiating edge-fed broadband double-layer microstrip patch antenna are mainly introduced to understand the research progress and expectation of today's microstrip antennas. This paper firstly introduces the basic theoretical concept of microstrip antenna, then introduces the cavity mode theory, and then mainly lists and introduces three kinds of designed microstrip antenna structures. Finally, these three types of microstrip patch antennas are analyzed. And the advantages, disadvantages, and development fields of the corresponding types of microstrip patch antennas are introduced. The application determines the structure of the method used, and each design has its strengths. Microstrip antennas always have room for research, and continuous research will be applied to more fields.

Keywords: Microstrip Antenna, U-Slot, Circular Polarization, Non-Radiating Edge Feeding, Wide Band

1. Introduction

In 1935, G.A. Deschamps first proposed the concept of the microstrip antenna, but it did not get much research attention then. Until 1972, due to microwave integration technology's development and the demand for space technology for low profile antennas, with the development of microwave integration technology and the emergence of various low power consumption dielectric materials, researchers such as R.E. Munson and J.Q. Howell made the first microstrip antennas. 1979 International Conference on Microstrip Antennas was held at New Mexico State University, and in 1981 IEEE Antennas in Propagation magazine published a special issue on microstrip antennas in January and made microstrip antennas a specialized branch in the field of antennas [1,2].

Due to the development of microelectronics and large-scale integrated circuits, the problem of too large and bulky antennas in electronic devices has become prominent, and small antennas that can coordinate with the device size and have effective electrical performance are urgently required. In most cases, the antenna size reduction will weaken the antenna's performance. And microstrip antenna has the advantages of being lightweight, low profile, and easy to co-form with other objects. Therefore, it has been used in many applications, such as satellite communication control technology, missile telemetry, and biomedicine. Microstrip patch antenna also suffers from narrow frequency bands, poor polarization purity, large parasitic feed amplitude, and limited power capacity [3,4].

Microstrip antenna belongs to the one-dimensional miniaturized resonant antenna, so the Q value is high, and the frequency band is narrow. U-slot and double-layer patch in the slot hole coupling and probe coupling feeding method can get about 40% of impedance bandwidth. Under normal conditions, the circular polarization bandwidth is often much lower than the impedance bandwidth. The conventional circular polarization microstrip axial ratio bandwidth will not exceed 1%. Thus, the factors that restrict the frequency of circular polarization microstrip antenna will change to polarization characteristics and gain. Along with the rapid development of wireless communication technology, in the field of radar, communication and positioning system are eagerly demanded dual-frequency / dual-polarized microstrip antenna to achieve the purpose of antenna sharing, frequency multiplexing, and transceiver work at the same time. The main goal of current dual-band antennas is to obtain double wideband characteristics with a controllable dual-band ratio [5, 6].

Traditional microstrip antennas have obvious disadvantages due to the impedance and narrow bandwidth disadvantages, making it difficult for microstrip antennas to be widely used. This article introduces three kinds of microstrip antenna design to provide ideas to increase the bandwidth problem. Firstly, the background of the microstrip patch antenna and the future development trend of the microstrip patch antenna are briefly introduced. The basic theoretical concepts of the microstrip patch antenna and common analysis methods of microstrip patch antenna are introduced. Finally, three types of microstrip patch antennas are listed: U-shaped slotted laminated broadband microstrip antenna, dual frequency circularly polarized laminated microstrip antenna, and non-radiating edge-fed broadband double-layer microstrip patch antenna. The structure of these three types of microstrip patch antennas is briefly introduced. The advantages and disadvantages of these three types of microstrip patch antennas are analyzed, as well as their application fields. All three antennas are miniaturized antennas, smaller than the size and weight of traditional antennas, which are more suitable for aerospace, automotive, mobile communication, and other applications.

2. Theoretical Analysis of Microstrip Antennas

2.1 Basic concepts of microstrip antenna

2.1.1 Structure and classification of microstrip antennas

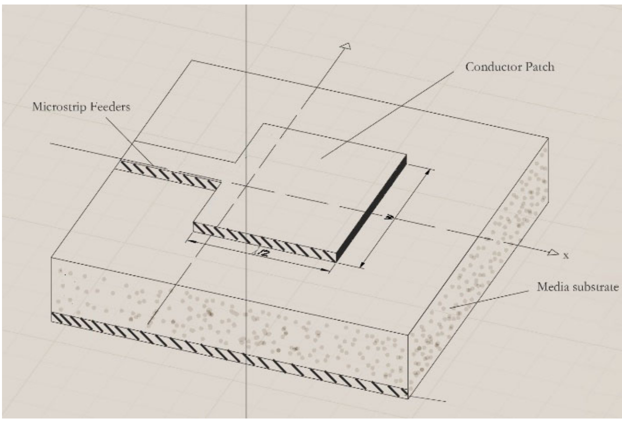

Figure 1. The schematic of microstrip antenna

The structure diagram of the microstrip antenna is shown in Figure 1. In a dielectric substrate whose thickness is much less than the wavelength, a thin metal layer is attached on one side as a ground plane by printed circuit or microwave integration techniques. The other side uses photolithography etching and other methods to make a certain shape of the metal patch. It then uses the tape line or Tongzhou probe to feed the patch, thus constituting a microstrip antenna [7]. Microstrip antennas can then be divided into three microstrip antennas according to their structural characteristics: microstrip patch antenna, microstrip traveling wave antenna, and microstrip slit antenna. Microstrip patch antennas are mainly composed of three parts, which are dielectric substrate, ground plate, and radiation patch. The radiation patch has various shapes. The common shapes are rectangles, circle, and polygons. When a patch is an area unit, it is called microstrip patch antenna; If the patch is a long, thin strip, it is called a microstrip vibrator antenna [8]. Microstrip traveling wave antennas are also composed of three parts: the substrate and the chain period structure on the substrate or a normal long TEM wave transmission line and the grounding plate. Microstrip slit antennas consist of a microstrip feed line with a slit in the grounding plate. Various feed methods include microstrip line side feed, coaxial line bottom feed, electromagnetic coupling, caliber coupling, and so on.

2.1.2 Microstrip antenna advantages and disadvantages

Table 1. Microstrip antenna versus conventional antenna

	Volume	Frequency Band	Gain	Conformal Capability	Application frequency
Microstrip Antenna	Small	Narrow	Low	Strength	Low and middle frequency band
Conventional Antenna	Large	Broad	High	weakness	High-frequency band

Because of its planar structure, microstrip antenna is easy to conform with the surface of carriers such as missiles and satellites, and can be integrated with circuits or active devices to form a single module. Due to the simple shape of microstrip antenna material, the basic material is dielectric substrate and mature processing technology, it is suitable for mass production of printed circuit technology. The antenna performance is diverse and can easily realize multi-functional work such as dual frequency, dual polarization and circular polarization. Disadvantages are also very prominent. As the conductor and dielectric will form excitation surface wave, thus loss. Because of the patch structure, it can only be received and radiated in half space. Frequency band, radiation efficiency and gain is also lower, the type of material and the advantages and disadvantages will also affect the performance.

2.2 Microstrip antenna analysis method

As the design of microstrip antenna analysis is based on specific requirements, it is necessary to calculate the performance index of the antenna in advance, so to reduce the workload and avoid unnecessary errors during antenna simulation. There are many basic methods to analyze the Vtech antenna, among which the main and most basic methods are the transmission line method, resonant cavity model method, Green's function method, and integral equation method. Each method has its advantages and disadvantages and complements each other to calculate various problems in microstrip antennas. Theoretical analysis methods can be found corresponding to all forms of antennas known so far [9].

2.2.1 Full wave analysis method

The full-wave analysis method, also known as the integral equation method [10,11], has the most rigorous and difficult analytical procedure and is computationally intensive. It is necessary to reduce the computational complexity by assuming the field source distribution in advance by following a priori model. The full-wave analysis method has generality and accuracy, and can be used for all kinds of feed methods and microstrip antenna analysis, and the results are accurate. The full-wave analysis method is mainly applied in the dielectric substrate part. This part of the transmission line method and cavity mode theory can not be well calculated. The full-wave analysis method is applied to computer simulation software, such as CST, ADS, etc., to a certain extent to shorten the microstrip antenna development time and development difficulty, more widely promote and develop antenna technology.

2.2.2 Cavity mold theory

The cavity mode theory is the most widely used theory for theoretical analysis of microstrip antennas, which includes single mode theory and multimode theory. In this thesis, only single-mode theory is used. The principle is that microstrip antenna and microstrip resonant cavity have similar structural shape. So the theoretical analysis of microstrip antenna can be converted into the theoretical analysis of resonant cavity. The regional internal field problem between the microstrip radiation element and the ground plane can be converted into the dielectric resonant cavity's internal field problem to solve the microstrip antenna's basic parameters.

The cavity mode theory approach is based on three assumptions. The microstrip patch and the field between the grounding plate are all by the incident field and the reflected field composition. The electric field component can not have other components, only the y-axis component. Microstrip patch and grounding plate in the propagation of the TEM wave has the magnetic field component can only have x-axis and y-axis direction. The magnetic field and electric field are independently existing quantities and will not change because of the change of coordinate z. Due to the equivalence principle, the microstrip antenna is equated to a dielectric resonant cavity, the electric wall is equated to the upper and lower surfaces of the cavity, and the magnetic wall is equated to the surrounding of the cavity. Due to the equivalence principle, the feedband feed line will be replaced by a current source parallel to the z-axis[12].

Based on the above three assumptions, the feed point can be found in any position, the basic parameters of the microstrip antenna.

The fluctuation equation of the passive region in the resonant cavity:

$$\left(\nabla^2 + \mathrm{K}^2\right)\overline{E} = 0 \quad (1)$$

$$K = \omega\sqrt{\mu\varepsilon} \quad (2)$$

The ω is the angular frequency, The μ is the relative magnetic permeability, The ε is the relative permittivity.

Assume:

$$\overline{E} = \overline{z}E_z(x, y) \quad (3)$$

Simplification

$$\left(\nabla_t^2 + \mathrm{K}^2\right)\overline{E_z} = 0 \quad (4)$$

$$\overline{H} = \frac{\overline{\mathrm{z}}\nabla_t E_z}{j\omega\mu} \quad (5)$$

The subscript t means that the equation operates only in the horizontal coordinate.

$$E_Z = E_0 \cos\frac{m\pi}{a}\sin\frac{n\pi}{b} \quad (6)$$

$$H_x = j\frac{n\pi E_0}{\omega\mu a}\cos(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y) \quad (7)$$

$$H_y = -j\frac{n\pi E_0}{\omega\mu a}\sin(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y) \quad (8)$$

And because

$$E_0 = \frac{V}{h} \quad (9)$$

V is the excitation voltage, m, n are denoted as non-zero integers. And m, n satisfy the following equation:

$$(\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2 = k^2 \quad (10)$$

Among them, rectangular microstrip antenna commonly used base mode m = 0, n = 1, the value of substitution to find the basic parameters of microstrip antenna.

3. Three kinds of microstrip antenna introduction

3.1 U-shaped slotted laminated broadband microstrip antenna

This microstrip patch antenna uses a matrix patch with a U-shaped slit, and the patch is filled with air or foam between the patch and the grounding plate due to the U-shaped slit structure. The slit edge current also introduces additional resonance, and the slit introduces capacitive resistance, both of which cancel with the inductive resistance of the probe to extend the frequency band.

Figure 2. of the gray area for the 3-layer consistent thickness of 1.5mm microwave F4B dielectric material copper-clad board, the media into 3 layers to be named from top to bottom with media 1 ~ 3, the center media 2 selected ε= 2.9 media, the edge media 1, 3 using ε= 2.2 media. In order to pull the resonant frequency point of the upper and lower layers of the patch, before using the dielectric constant difference between the copper-lined plate. In contrast, the upper and lower patches are made

of Rohacell 71HF (ε=1.07) foam, the laminated structure of the foam reduces the average node constant of the antenna, thus allowing a lower Q value, a wider frequency band, and higher efficiency of the radiation [13]. Because the parasitic patch laminated microstrip antenna has 2 resonant frequencies, opening U-shaped slits in the rectangular microstrip patch antenna can change the current flow on the patch surface, thus forming a surrounding current and generating a new resonant frequency [14]. However, this will lead to more resonant frequency points of U-shaped open slit stacked microstrip antenna, more factors affecting parameters, and variable and flexible design, so there will be some difficulties in the design. The patch length L's upper and lower layers have a corresponding resonant frequency point. Changing the size of the patch can affect the resonant frequency point. Enlarging the patch can reduce the resonant frequency point, and reducing the patch can increase the resonant frequency point.

It is necessary to adjust the frequency interval between the resonant frequency points corresponding to the upper and lower patch layers by changing the foam's thickness between the upper and lower patches. As the thickness of the foam is continuously adjusted to make the resonance points of the upper and lower two layers of patches appear in the frequency band simultaneously, the final parametric coupling is achieved. Among them, when the simulation is carried out because the relative position of the U-seam of the upper and lower two layers of the patch will determine the amount of coupling, it need to focus attention. By decreasing the horizontal spacing between the upper and lower U-seams, the coupling amount can be increased, thus reducing the frequency point echo parameters and obtaining better simulation results. Theoretically, the double-layer structure should get four resonant frequencies because the single-layer U-slit microstrip antenna has two resonant frequencies. Still, in the actual simulation results, one of the four resonant frequencies is too far away from the other three resonant frequencies, resulting in the inability to adjust all four resonant frequencies to the band. The relative impedance bandwidth reaches 24.05%. Compared with the general matrix patch antenna with larger bandwidth, the U-shaped open slit laminated microstrip antenna can be applied to different environments by adjusting the patch length and width, changing the media, foam type, and thickness. The horizontal spacing of the double U-shaped slit, so that the U-shaped open slit laminated microstrip antenna can be used in different environments [15].

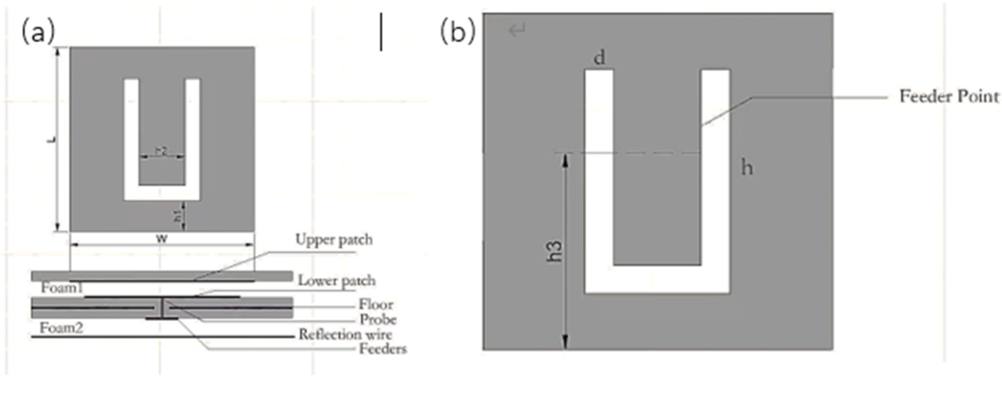

Figure 2. The schematic of U-shaped slotted laminated broadband microstrip antenna

3.2 Dual frequency circularly polarized laminated microstrip antenna

Dual frequency circularly polarized antenna is widely used in radar, satellite communication, and positioning system. The laminated structure has good conformal ability and can work with two resonant frequencies. Each frequency can get a wider band, and both frequencies can get a larger bandwidth and higher gain. Microstrip antennas with larger dual frequency ratios can be obtained using two substrates with different dielectric layers.

The antenna's polarization can illustrate circularly polarized waves [16,17]. Antenna polarization refers to the trajectory of the power plant vector break in a fixed position in space with time motion, according to the polarization form of the antenna can be divided into three different forms: line polarized antenna, far polarized antenna, and elliptically polarized antenna [18-20].

The single-point feed method achieves dual frequency dual circular polarization through the laminated structure. This paper uses a rectangular patch and two circular patches through the laminated structure to achieve dual frequency dual circular polarization. The upper and lower layers are made of FR4 (=4.4) dielectric material with a thickness of 1.6mm, and the antenna is fed through the coaxial. The coaxial line is fed through the lower patch to the upper patch, while the lower patch is fed through the upper coupling. By changing the upper layer circular patch radius to the upper layer circular patch size, the upper and lower layers of the patch antenna coupling strength are not changed significantly. The antenna structure is shown in Figure 3..

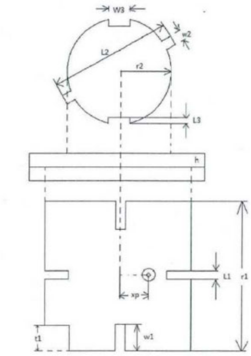

Figure 3. The schematic of Dual frequency circularly polarized laminated microstrip antenna

The designed laminated circularly polarized antenna with a circular patch on the top layer and a rectangular patch on the bottom layer with cut corners. The upper circular patch is slotted to reduce the size of the circular patch, which allows for adjusting the antenna impedance matching and circular polarization performance. The lower square layer is slotted to reduce the square patch size. Although slotting can reduce the antenna size to some extent, the antenna gain will be reduced at a cost, so the slotting size should be adjusted carefully to ensure the antenna performance. Compared with the traditional rectangular microstrip antenna, the dual-band circularly polarized broadband microstrip antenna has a smaller shape and wider bandwidth, which can be applied to fine instruments. But the disadvantages are more obvious because of the antenna surface slotting, which reduces antenna gain. Because of the dual side up and down structure, the antenna simulation also brings great trouble. And due to the laminated structure will be in the antenna ground, and the lower patch will be extremely parallel to the patch surface, thus affecting the antenna's performance [21].

3.3 Non-radiating edge-fed broadband double-layer microstrip patch antenna

The whole antenna consists of four parts: feed microstrip plate layer, foam layer, parasitic microstrip plate layer, and grounding plate layer. The antenna structure as a whole is shown in Figure 4..

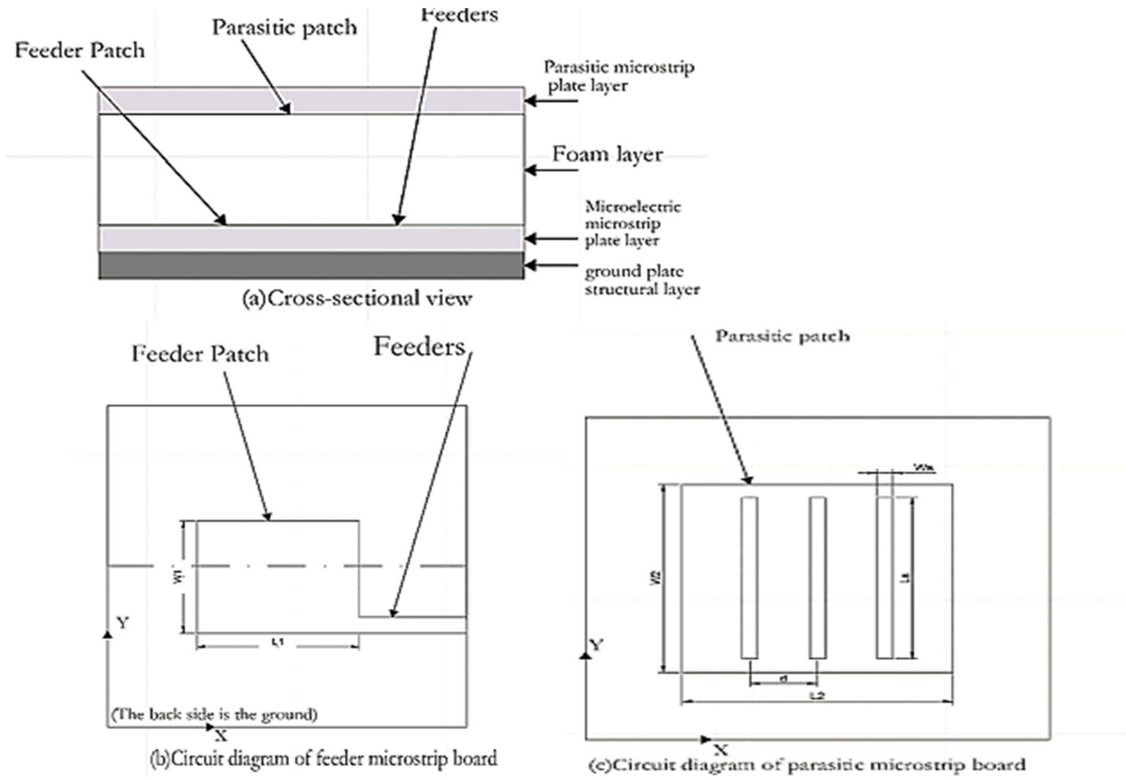

Figure 4. The diagram of non-radiating edge-fed broadband double-layer microstrip patch antenna

The two parts of the feed microstrip board are the etched feed patch and feed microstrip line. The parasitic patch is etched again on the microstrip board, and the antenna structure uses the inverted structure of the parasitic patch to protect the parasitic patch. The bottom layer is designed with a non-radiating edge feed of a microstrip line, which is different from the traditional double-layer microstrip patch antenna design. The advantage of this design is that it can simplify the design of the feed network. The disadvantage is that the antenna inevitably excites the TM01 cross-polarization mode in addition to the main mode TM01 mode, and the cross-polarization performance of the antenna is weakened. Adjusting the rectangular patch aspect ratio, to have been TM01 mode on the double-layer microstrip patch effect is limited.

Additionally, the antenna has a low radiation impedance, leading to the difficulty of matching broadband impedance and simulating and producing. Cutting the surface current of the cross-polarization mode can be achieved by shaving off the uniformly distributed patch in the direction of the parasitic patch perpendicular to the radiating edge to form a uniformly distributed slim gap to suppress the antenna cross-polarization mode. The laminated structure of the foam in the upper and lower patches reduces the average node constant of the antenna, thus making the Q value lower, the frequency band wider, and the radiation efficiency higher, and the antenna is fed through the coaxial. The coaxial line passes through the lower patch to feed the upper patch, while the lower patch is fed through the upper coupling. The thickness of the foam can be constantly adjusted to make the resonance points of the upper and lower layers of the patch appear in the frequency band simultaneously and, finally, reach the parametric coupling.

The non-radiating edge-fed broadband dual-layer microstrip patch antenna can be flexibly applied to the design of broadband coplanar centrally fed microstrip array antennas. Compared with the traditional radiating edge-fed dual-layer microstrip patch unit, the non-radiating edge-fed broadband dual-layer microstrip patch antenna can simplify the antenna array feeding circuit and improve the feeding efficiency more suitable for creating broadband and efficient coplanar-fed antenna array. And non-radiating edge-fed broadband double-layer microstrip patch antenna design coplanar fed microstrip matrix antenna design saves feed space, facilitates the design of large scan angle antenna array, and can show good performance index in a wider frequency band. It can be expected that the non-radiating edge-fed broadband double-layer microstrip patch antenna will have a broad prospect in radar and communication systems. Compared with the normal rectangular microstrip patch antenna, the non-radiating edge-fed broadband double-layer microstrip patch antenna has the advantage of being smaller and more concentrated. It will be widely used in the military and communication fields [22].

3.4 Study Comparison

Table 2. Three kinds of microstrip antenna comparison

Category	Difficulty of design	Conformal Capability	Applicable field
U-shaped slotted laminated broadband microstrip antenna	Middle	Middle	Most widespread, can be used in most fields
Dual-band circularly polarized laminated microstrip antenna	Hard	Good	Radar, GPS and other positioning systems
Non-radiating edge-fed broadband double-layer microstrip patch antenna	Simple	Bad	Military field and communication field

All three design methods have a huge progress compared with the traditional rectangular broadband microstrip antenna, and have a broader range of applications, which is the result of continuous research in recent times. As all three designs use a laminated structure, all can be adjusted by changing the type and thickness of the foam to adjust the frequency interval between the resonant frequency points of the two layers of the patch. By constantly adjusting the thickness of the foam so that the upper and lower sides of the patch resonance point at the same time appear in the frequency band, and finally achieve parametric coupling. The non-radiating edge-fed broadband double-layer microstrip patch is more suitable for creating broadband and efficient coplanar-fed antenna arrays due to its smaller and simpler design, which facilitates the design of antenna arrays with large scan angles and can show good performance index in a wider frequency band. Dual-band circularly polarized laminated microstrip antenna can also work in two resonant frequencies, obtaining a larger bandwidth and higher gain. The slotting process makes simulation and design most difficult

4. Conclusion

This paper firstly introduces the basic theoretical concept of microstrip antenna, then gives the common analysis methods of microstrip antenna, and finally mainly lists and introduces three microstrip antenna designs. The basic structures of U-slot stacked broadband microstrip antenna, dual-band circularly polarized stacked microstrip antenna, and non-radiating edge-fed broadband double-layer microstrip patch antenna are briefly introduced. The advantages and disadvantages of these three microstrip patch antennas are analyzed, and the developing fields of the corresponding types of microstrip patch antennas are introduced. In the face of different design requirements to choose different microstrip antennas, analyze the advantages and disadvantages of different antennas.

Due to the advantages of microstrip antenna, such as low cost, low profile, small space occupation, and high conformal capability, it is valued by researchers worldwide. Researchers all over the world are working to solve the narrow band problem of microstrip antenna. The three microstrip antennas cited are the design methods of microstrip patch, which are more mature and better than the traditional microstrip patch today. Microstrip antennas include the military, aerospace, medical, and so on.

Nowadays, people's life has microstrip antenna design all the time, with a wide range of development prospects, from military to people's livelihood, from communication to medical, from vehicle to aerospace. About the material medium of microstrip antenna is also a major research direction, how to design and make better material.

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