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Modeling analysis of patch antenna efficiency considering impedance matching characteristics of cable feed end

Lusheng Yang[1], Liyao Wang[2]

[1]*College of Computer and Communication, Lanzhou University of Technology, Lanzhou, 730050, China*
[2]*College of Engineering, Yanbian University, Yanji, 133000, China*

Abstract: *The small size of patch antenna makes its application scenarios diverse, and its research is quite extensive. However, the calculation of the influence of the applied excitation source and operating band on the overall operation of the antenna is very complicated, and the related modeling is less. Therefore, a patch antenna model with dual input feed is constructed by COMSOL based on the finite element analysis method. After considering the reasonableness of the coaxial cable insulation medium setting, the geometry structure of the patch antenna with dual input end feeding is constructed. The balanced antenna uses two input feeds, so in the balanced system, the operational performance of the antenna is changed by adjusting the two input signal excitation, so the spatial electric field distribution of the patch antenna under different operating frequencies is explored by applying different external applied excitation sources. Finally, the electric field change law of patch antenna under different operating working conditions is compared and analyzed, and the way to analyze the antenna operating performance is summarized.*

Keywords: *Patch Antenna, Antenna Structure, Double Ended Input Feed, Finite Element Method, Antenna Performance*

1. Introduction

With the advent of mobile communication information technology, the communication between people is becoming more and more close and diversified, and the demand for wireless communication devices is also increasing. With the advantages of small size, low cost, and easy manufacturing, patch antennas are now widely used in devices such as wireless LAN bridges, cell phones, and GPS handheld devices [1-2]. To accommodate complex applications, patch antennas are available in a variety of geometrical variations. The patch shape and structure directly affect the antenna parameters and functions such as radiation direction map, antenna efficiency and antenna impedance. Due to the complex relationship between antenna geometry and electromagnetic field, it is still challenging to determine the parametric properties of antennas by antenna shape and structure.

The use of traditional electromagnetic simulation of the antenna modeling to obtain the parameters of the antenna way of computing a large, time-consuming and inefficient. At the same time, in the process of antenna simulation, the engineer may for the design details of the antenna location, which will cause the difficulty of system simulation cannot be modeled. To overcome the problems of long simulation time and direct modeling difficulties, Tapan K. Sarkar proposed the scheme of equivalent modeling [3-4]. Equivalent modeling means to establish the equivalent model of an antenna by scanning its radiated near-field information, and then use the equivalent model for simulation analysis, which reduces the simulation time. Moreover, the equivalent modeling only needs the radiated near-field information, not the antenna or circuit design details, which avoids the problem of difficult direct modeling. Tapan K. Sarkar established the relationship between the equivalent flow and the radiated near-field through the integral equation, and if the radiated near-field data is known, the equivalent flow model can be obtained by solving the integral equation [5]. However, this method can only achieve accurate prediction of the radiation field in the region in front of the equivalent surface, and the error in the prediction of the far-field back flap of the antenna is larger. Yuri Álvarez further developed the equivalent flow method and proposed a reconstruction method for the equivalent flow on an arbitrary three-dimensional surface based on the integral equation, where the equivalent surface is an arbitrary closed surface that wraps the antenna, and the equivalent model can accurately calculate the radiation field outside the equivalent surface field outside the equivalent surface [6]. All of the above methods of equivalent modeling require accurate

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near-field magnitude and phase information. The more the number of near-field sampling points, the longer the near-field sampling time. To further improve the efficiency of the equivalent modeling, in the literature [7] only the tangential magnetic field data on the Huygens plane is used to build the equivalent model of the patch antenna. However, their equivalent modeling approach is to equivalently model the radiation source at a single frequency. In the literature [8], a broadband equivalent dipole model of patch antenna based on near-field amplitude information is implemented, and the position and number of dipole models are fixed for the whole frequency band, and the excitation value of dipole on the whole frequency band can be solved by interpolation method using only the known near-field data at certain frequency points, and both numerical and measured results show that the equivalent model has high accuracy. However, the equivalent modeling method will assume that the floor of the radiation source is infinite, which will ignore the bypass field at the edge of the floor, making the established equivalent model is not accurate. In addition, the assumption that the floor of the radiation source is infinite will also cause the equivalent model cannot calculate the rear flap of the antenna. In contrast, the intelligent algorithmic model [9-12] is not conducive to fast analysis due to its inherent shortcomings, conditional limitations in the antenna parameter model, and complex and time-consuming computations.

In summary, for the problem that there are few simulation models for the influence of external applied excitation source and operating frequency on the operational performance of planar patch antenna, this paper constructs a patch antenna simulation model based on finite element method that can model different external applied excitation sources and different operating frequencies. Firstly, the geometric structure of patch antenna with double-fed input is constructed, and the rationality of insulating medium setting of coaxial cable is considered; secondly, the spatial electric field distribution of patch antenna under different external applied excitation sources and different operating frequencies is explored respectively; finally, the electric field change law of patch antenna under different operating conditions is compared and analyzed, and the way of analyzing antenna operating performance is summarized.

2. Fundamental principles

2.1 The basic principle of patch antenna structure in wireless network communication system

Mobile communication refers to the transmission and exchange of information between at least one of the two communicating parties on the move (or temporarily staying at a non-predetermined location), which includes communication between mobile bodies and mobile bodies and communication between mobile bodies and fixed points, mobile communication devices transmit through a form of signal and energy propagation - radio waves Information. A section of metal wire in the alternating current can launch alternately changing induced electric field and induced magnetic field into space. According to Maxwell's electromagnetic field theory, the changing electric field and changing magnetic field are interdependent and mutually excited, alternately generated, and radiated out in space at a certain speed from near to far, which is the emission of radio waves. On the contrary, the alternating electromagnetic field in space can induce alternating current when it meets the metal wire - antenna, which corresponds to the reception of radio waves. In this paper, the study of cell phone antenna design commonly used in the plane inverted F-type antenna abbreviated 3D diagram is shown in Figure 1. The basic function of the antenna is to radiate and receive radio waves, which transforms the guided waves propagating on the transmission line into electromagnetic waves propagating in the unbounded medium (usually free space), and radiates and receives the strong directionality of space electromagnetic waves, creating its ability to transmit and receive wireless signals. The difference between the antenna and the general metal body is that the antenna emphasizes the most effective transformation of the alternating current in the metal body into the electromagnetic wave in space, or the most effective transformation of the electromagnetic wave in space into the alternating current signal in the metal body. According to the reciprocity theorem of antenna, the same antenna as transmitting or receiving the basic characteristic parameters are the same, that is, the same vice antenna can be used as both transmitting antenna and receiving antenna. Generally will mainly use the transmitting antenna to tell the main characteristic parameters of the antenna [11], with these characteristic parameters can be a good analysis of the antenna the energy of the high frequency current transmitted between the conductors change into the electromagnetic wave energy in space, and according to the required radiation out the ability of the size.

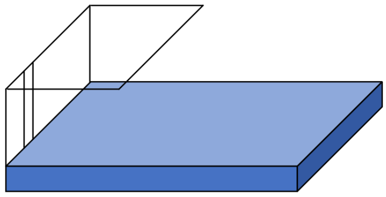

Figure 1: PIFA 3D structure diagram

2.1.1 Directional functions and directional maps

The directional coefficient of the antenna then for the antenna radiation characteristics and its spatial orientation of the function of the relationship. At a fixed frequency, the directional function of the antenna's far field area radiation is shown in (1), when the normalized directional function of the frequency point is shown in (2). Because the general use of cell phone antenna antenna form for the monopole and PIFA antenna, they directional map have omnidirectional, so in the design of the time, generally do not give special consideration to its directional map.

$$f(\theta,\varphi)=\frac{|E(r,\theta,\varphi)|r}{60I} \tag{1}$$

$$F(\theta,\varphi)=\frac{f(\theta,\varphi)}{f_{\max}(\theta,\varphi)} \tag{2}$$

Where *E(r,q,j)* denotes the radiation field in the far zone of this frequency point in the direction of the spherical coordinate system *(r,q,j),* and I is the imputed current.

2.1.2 Antenna efficiency

The efficiency of the antenna is the ratio of the antenna's radiated power (Pr) to the input power (P_{in}), that is, the antenna will feed point at the input power radiation out of the ability. Input power is part of the antenna in the conductor transmission or media loss, for loss power P_L. Defined loss resistance for R_L, equivalent radiation resistance for R_r,so it can be the antenna in the radiation efficiency formula with the concept of equivalent circuit to interpret, as shown in (4). For the cell phone built-in antenna, the efficiency is required to be at least 30%. If you want to increase the efficiency of the antenna, you need to reduce the resistance of the loss resistance by maximizing its equivalent radiation resistance at the same time.

$$\eta=\frac{P_r}{P_{in}}=\frac{P_r}{P_r+P_L} \tag{3}$$

$$\eta=\frac{P_r}{P_r+P_L}=\frac{R_r}{R_r+R_L} \tag{4}$$

Where Pr is the radiated power of the antenna,P_{in} is the input power, P_L is the loss power, R_L is the loss resistance, R_r is the equivalent radiation resistance.

2.1.3 Input impedance and characteristic impedance

The ratio of the signal voltage and signal current at the input of the antenna, called the input impedance of the antenna Z_{in}, the formula as shown in (5) formula. The input impedance is related to the structure, size and working wavelength of the antenna. Reactance component will reduce the antenna from the feed line to the signal power extraction, so must make the reactance component as far as possible for zero, that is, as far as possible to make the antenna input impedance is pure resistance. For any antenna, through the antenna impedance debugging, in the required working frequency range, so that the input impedance of the imaginary part is very small and the real part is quite close to 50 ohms, when the antenna and the feed line in a good impedance match. So after the input impedance of the antenna, you can design the corresponding feed line according to the value.

Characteristic impedance is the impedance at a certain frequency at the transmitting end of a uniform cable when it is infinitely long. Characteristic impedance is the most important factor affecting the quality and integrity of the signal. If the impedance remains consistent between the propagation intervals of adjacent signals during signal propagation, then the signal can propagate forward very smoothly. If there is a difference between adjacent signal propagation intervals, part of the energy in the signal will be reflected back, and the continuity of signal transmission will be destroyed, which will bring problems such as large return loss, increased signal transmission radiation, and insufficient signal transmission integrity. The characteristic impedance of coaxial cable is shown in (6), which shows that the characteristic impedance of coaxial cable is a combination of cable conductivity, capacitance and resistance, independent of the feeder length, operating frequency and load impedance connected to the feeder terminal.

$$Z_{in} = \frac{U_{in}}{I_{in}} = R_{in} + jX_{in} \tag{5}$$

$$Zc = \frac{60}{\sqrt{\varepsilon_r}} \times \ln(\frac{D}{d}) \tag{6}$$

Where, R_{in} the input resistance of the antenna; X_{in} is the input reactance of the antenna; *D is the inner* diameter of the outer conductor of the coaxial cable; *d is the* outer diameter of the inner conductor of the coaxial cable; e_r is the relative dielectric constant of the insulation medium between the conductors.

2.1.4 PIFA balanced patch antenna

In this paper, we select the PIFA balanced antenna which is commonly used in the current design engineering of cell phone antenna for modeling analysis.PIFA antenna has the advantages of small size, light weight, low SAR value, and can achieve multi-frequency coverage. At the same time it is quarter wavelength resonant mode, which has the characteristic of very easy to do the frequency matching.

The basic structure of PIFA antenna includes four parts: ground plane, radiation unit, short-circuit metal sheet and coaxial feed line. The ground plane can be used as a reflective surface, the radiation unit is a metal sheet parallel to the ground plane, the short-circuiting metal sheet is used to connect the radiation unit and the ground plane, and the coaxial feed line is used for signal transmission. The simplest PIFA antenna is a metal sheet placed parallel to the ground plane, with coaxial line or microstrip line feed can be. Its radiation mainly depends on the edge field. The key parameter to control the bandwidth of PIFA antenna is *H*, the distance between the patch and the ground. By adjusting the total length L_1~L_2, the operating frequency of the antenna can be adjusted. In practice, L_1 should be similar to the width of the PCB to obtain a wider bandwidth. The antenna structure diagram is shown in Fig.2.

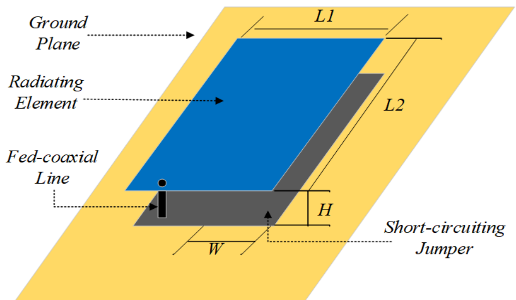

Figure 2: PIFA balanced antenna structure diagram

For PIFA antennas, the resonant frequency is proportional to the sum of its length and width. As shown in Fig.3, the width of a PIFA plus its length is about a quarter of a wavelength at its resonant frequency.

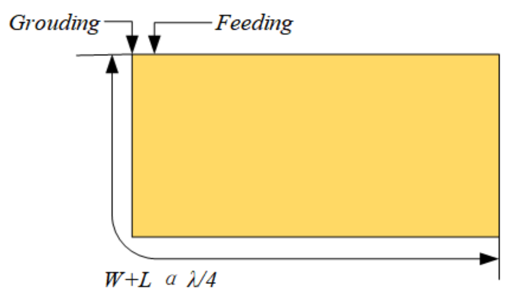

Figure 1: Estimated resonant frequency of PIFA

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2.2 RF and tuning analysis principle of wireless communication network

In this paper, the PIFA balanced antenna is fed using two inputs, so there is less interference to the whole system through the ground plane. In the balanced system, the phase and amplitude of the two input signals are adjusted so as to change the performance of the antenna. The antenna as a whole is mathematically modeled using COMSOL to solve for the linearity of the electric field and to calculate the radiated energy, far-field pattern, gain, directivity, impedance and S-parameters. The electromagnetic energy of the antenna transmitted and received radiation is also derived.

To simplify the difficulty of setting boundary conditions, we use the ideal electric conductor condition. Two coaxial cables are fed to the patch antenna from both sides. The characteristic impedance Z_{ref} is determined by setting the inner diameter *D of the* outer conductor of the coaxial cable, the outer diameter *d* of the inner conductor of the coaxial cable, and the relative dielectric constant e_r of the insulation medium between the conductors. The amplitude of the incident voltage wave from the transmission line is equal to V_0, and a portion of the voltage wave is reflected directly at the port, depending on how well Z_{ref} matches the characteristic impedance of the coaxial cable. Thus, for each coaxial cable, when the antenna impedance matches the impedance of the coaxial cable, theoretically the maximum power can be generated in the antenna, and this power is calculated by the following (7) equation. At this time, the antenna efficiency can be calculated by (8) formula, and the antenna best working frequency.

$$P_{\max} = \frac{V_0^2}{2Z_{ref}} \tag{7}$$

$$k_0 = \omega\sqrt{\varepsilon_0 \mu_0} \tag{8}$$

Where V_0 is the peak time-harmonic applied voltage; P_1 is the net power flow at port 1; and P_2 is the net power flow at port 2.

The whole antenna is modeled in three-dimensional mode. In addition to the electromagnetic field in the medium, most of it is in the air domain, generally speaking the air domain is around one to two wavelengths, but in practice, the air domain is much larger than that range. When modeling, we use a thin layer, the perfectly matched layer (PML), to solve the problem of the air domain range. There are damping materials and materials with attenuation properties inside the thin layer, so when the electromagnetic waves reach the thin layer, they will be completely absorbed and no echo will be generated, and the air domain can be equated to an infinite space. In addition, scattering boundary conditions are added outside the PML to further reduce reflections.

Under the above conditions, since the signal is time-harmonic, we can solve the Helmholtz equation for the electric field vector at any position of the geometric structure, as shown in equation (9). Meanwhile, the calculation of the far-field domain can be performed, and the far-field distribution at infinity can be obtained, and the calculation equation is shown in equation (10). Through the above modeling analysis, the functional characteristics of the balanced patch antenna can be explored.

$$\nabla \times \mu^{-1}(\nabla \times \boldsymbol{E}) - k_0^2 \varepsilon_r \boldsymbol{E} = 0 \tag{9}$$

Where *m* is the magnetic permeability and k_0 is the phase shift constant in free space, defined as *k_0=2p/l*.

$$\boldsymbol{E}_{far} = -\frac{jk}{4\pi}\boldsymbol{r}_0 \times \int [\boldsymbol{n}\times\boldsymbol{E} - \eta\boldsymbol{r}_0 \times (\boldsymbol{n}\times\boldsymbol{H})]\exp(jk\,\boldsymbol{r}\cdot\boldsymbol{r}_0)d\,\boldsymbol{S} \tag{10}$$

where $\boldsymbol{r}_0$ is the unit vector in spherical coordinates ***r*** and the rest of the parameters are in vector form in the corresponding form.

3. Model construction and result analysis

3.1 Model Definition

There is a complex relationship between the geometric structure of the antenna and the electromagnetic field, and different shapes and structures will produce different antenna performances.

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The input feed terminal is used as the interface of the external excitation source of the antenna, and the matching degree of its impedance value and the impedance value of the antenna structure directly affects the operation efficiency of the antenna. In this paper, a typical dual-fed input planar patch antenna is selected as the research object to investigate the efficiency of the patch antenna under different operating frequencies and different externally applied voltage excitation. The solid geometry of the model is shown in Fig.4, which mainly includes coaxial cable feed input, PCB board and patch antenna connection conductor. The coaxial cable contains an outer conductor with an inner diameter of 5 mm and a center conductor with a diameter of 2 mm. The gap between the conductors is filled with a solid insulating material with a dielectric constant of 2.2, and the two coaxial cables feed the patch antenna from both sides; the side length of the PCB is 100 mm and the thickness is 1 mm. the structure of the patch antenna located in the middle of the PCB board is 15 mm × 15 mm, and it is connected to the feed input through two conductors with widths of 0.8 and 0.6 respectively.

The model adopts the boundary conditions of the aggregate port to simulate the matching characteristics of the patch antenna and the transmission line feed impedance, and adopts the physical field-controlled mesh dissection method. By taking into account the problems of model accuracy and computational time scale requirements, the important structures such as the feed input terminal and the patch antenna are grid polarized, and the air domain and the PCB board are grid coarsened, based on the unstructured tetrahedral mesh The model is divided into finite element domains based on the principle of unstructured tetrahedral mesh segmentation.

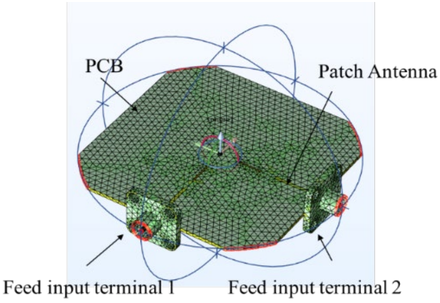

Figure 4: Geometric model of the patch antenna and mesh sectioning

3.2 Simulation results and analysis

The balanced antenna uses two input feeds, so in the balanced system, the operating performance of the antenna can be changed by adjusting the excitation of the two input signals. In this paper, we investigate the electric field distribution on the surface of the patch antenna when the antenna operates at 6.2 Ghz, 6.22 Ghz, 6.24 Ghz, 6.26 Ghz, 6.28 Ghz and 6.3 Ghz with 1V, 3V and 5V excitation voltages respectively, and the simulation results are shown in Fig.5, 6 and 7.

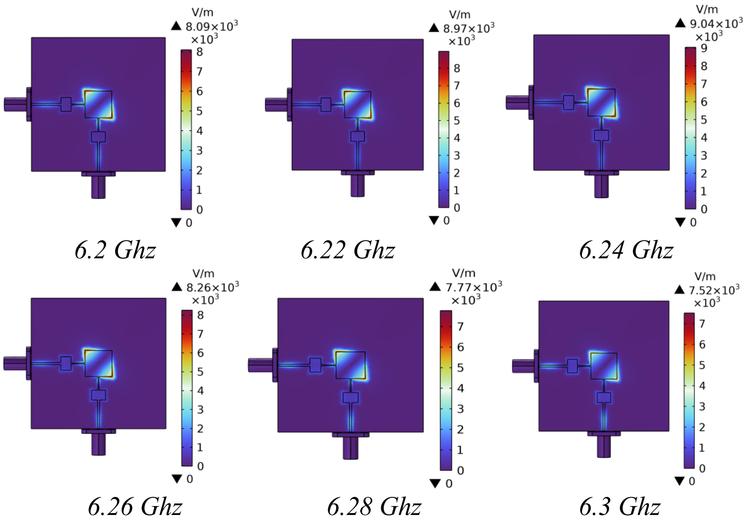

Figure 5: The electric field distribution on the surface of the patch antenna at different frequencies when the externally applied excitation voltage is 1V

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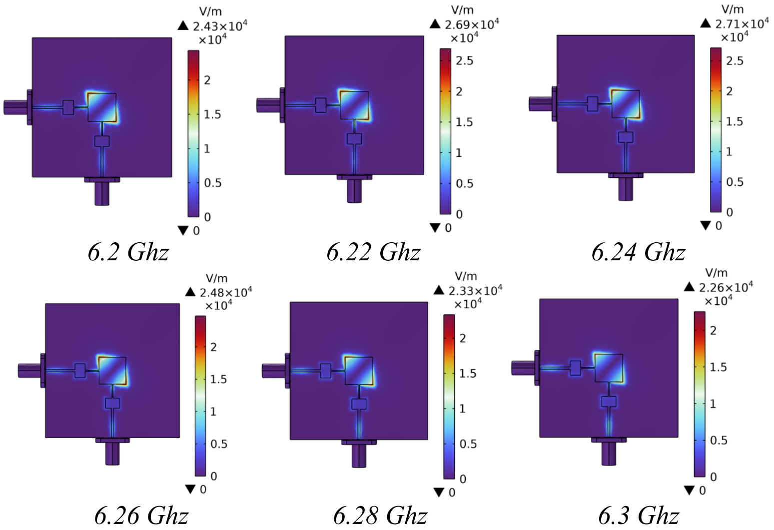

Figure 6: Surface electric field distribution of patch antenna at different frequencies with externally applied excitation voltage 3V

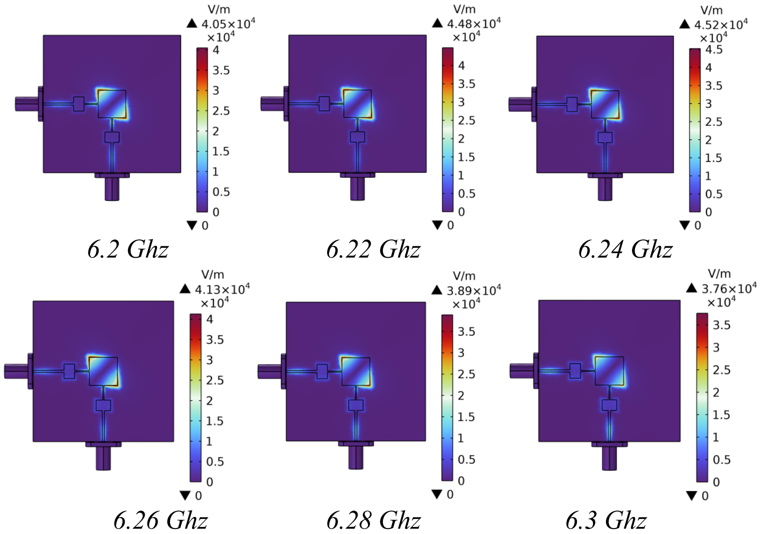

Figure 7: Patch antenna surface electric field distribution under different frequencies when the externally applied excitation voltage is 5V

From the analysis of the simulation results in Figure 5, 6 and 7, it can be seen that when the external applied excitation source at the input of the dual-feed is kept constant. The maximum value of the spatial electric field borne by the antenna circuit decreases gradually as the operating frequency of the patch antenna increases, when the amplitude of the external applied excitation source is 1V. The maximum spatial electric field value decreases from 8.09×10^3 V/m to 7.52×10^3 V/m, decreasing by 7%. When the amplitude of the external excitation source is 3V, the maximum electric field value in space decreases from 2.43×10^4 V/m to 2.26×10^4 V/m, decreasing by 7.1%. When the amplitude of the external excitation source is 5V, the maximum electric field value in space decreases from 4.05×10^4 V/m to 3.76×10^4 V/m, decreasing by 7.2%. Thus it can be seen that the increase of the excitation voltage increases the maximum electric field value in space, but with the increase of the frequency. Therefore, the best operating frequency of patch antenna and the external applied excitation voltage should match each other. So that the corresponding excitation voltage can be provided at the corresponding operating frequency to meet the functional requirements of patch antenna operation.

4. Conclusions

There is a complex relationship between the geometric structure of the antenna and the electromagnetic field, different shapes and structures will produce different antenna performance, the input feed terminal as the external excitation source interface of the antenna, its external applied

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excitation source and the operating frequency of the antenna directly affect the antenna performance. In this paper, by constructing a certain simplified planar patch antenna structure, applying different excitation sources and different operating frequencies of the model antenna, the following conclusions are obtained:

(1) when the dual-fed input external applied excitation source is kept constant, with the increase of the patch antenna operating frequency, the maximum value of the space electric field borne by the antenna circuit is gradually declining, the higher the voltage, the greater the degree of decline;

(2) when the patch antenna operating frequency remains unchanged, with the double-fed input external applied excitation source amplitude increases, the antenna circuit withstands the space electric field in gradually increasing, the greater the frequency, the greater the rising degree.

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