IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Research on the Development of Frequency Reconfigurable Antenna and Polarization Reconfigurable Antenna

To cite this article: Yanzhuang Yin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **242** 022051

IOP Conf. Series: Earth and Environmental Science **242** (2019) 022051 doi:10.1088/1755-1315/242/2/022051

Research on the Development of Frequency Reconfigurable Antenna and Polarization Reconfigurable Antenna

Yanzhuang Yin[1, *], Mingming Lv[1], Long Ma[1], Xubao Sun[1]

Corresponding Author: Yanzhuang Yin

[1]College of Electronic, Communication and Physics, Shandong University of Science and Technology, Qingdao, China

Abstract: With the rapid development of science and technology, it is an inevitable trend for wireless communication systems to work on the same platform in different frequency bands. Reconfigurable antenna realizes the reconfiguration of parameters such as resonant frequency, polarization mode and radiation direction. The function of traditional multi-antennas can be realized by a single antenna. This paper presents a frequency reconfigurable antenna, which is especially suitable for multi-band and single-band hopping network communication systems. The simulation results show that the bias network has little effect on the antenna performance. In this paper, a polarization reconfigurable clover antenna fed by coplanar waveguide is proposed, which can realize switching function between left-handed circular polarization and right-handed circular polarization.

1. Introduction

In recent years, new communication technologies have emerged with the rapid progress of science and technology. The rapid development of satellite communication and cellular communication systems, as well as the excellence of many sophisticated systems such as electronic countermeasures, satellite navigation and deep space remote sensing, constantly stimulates and promotes the research of wireless technology. Driven by this development trend, wireless information system is moving towards the direction of large capacity, multi-function and high efficiency. Expanding system capacity, increasing system function and improving system efficiency through effective technical means can not only reduce system cost, but also meet the expanding system demand. However, in the further development of wireless communication system, people can only place multiple antennas on the same platform to meet the demand, which causes the system cost increase, carrier weight is too large, system electromagnetic compatibility deterioration, radar cross section is difficult to reduce and other issues, greatly restricting the development of wireless communication system. The research concept of reconfigurable antenna is to change one or several electrical parameters of the antenna in real time according to the demand, so as to adjust the working state of the antenna at any time. This not only reduces the number of antennas on the carrier platform, but also makes up for the lack of EMC among the system components, effectively alleviating the constraints of the number of antennas on the development of wireless communication.

The reconfigurable antenna can be divided into frequency reconfigurable antenna, Polarization Reconfigurable antenna, pattern reconfigurable antenna and hybrid reconfigurable antenna according to its functions, which can realize two or more reconfigurable functions at the same time. As a viable alternative, frequency reconfigurable mobile phone antenna emerges as the times require. Frequency reconfigurable antenna can be regarded as narrowband antenna, which has both filter function and greatly reduces the requirements of the system for filter. Therefore, frequency reconfigurable mobile phone antenna has important application requirements. Frequency reconfigurable antenna can adjust its operating frequency in broadband or between multi-frequency points and maintain stable radiation characteristics. Frequency conversion and frequency hopping communication can increase confidentiality, enhance anti-jamming ability and eliminate multipath effect in wireless systems. In addition, the flexible performance of frequency reconfigurable antenna can also cooperate well with the back-end processing module, so that the antenna can adjust its working state in time in different systems and changeable application environments, and ensure the stability of communication quality. Polarization reconfigurable antenna can adjust the polarization state of radiated electromagnetic wave. Using polarized reconfigurable antenna in wireless communication system can change the polarization mode of space electromagnetic wave in real time according to the working environment, restrain the signal fading caused by multipath propagation of electromagnetic wave, and improve the spectrum utilization. In this paper, the frequency reconfigurable antenna and polarization reconfigurable antenna are studied, and the physical mechanism and design difficulties are described in detail.

2. Theoretic basis of frequency reconfigurable antenna and polarization reconfigurable antenna

2.1 Parameters

Reflection coefficient. Ideally, the input impedance of the antenna is equal to the output impedance of the circuit, so that the current in the circuit can be fully fed into the antenna part. In fact, it is impossible to achieve a perfect match, that is, there will be reflected waves. In this case, the reflection coefficient in the circuit is equal to the square root of the ratio of reflection power to incident power. It can also be expressed as the ratio of the reflected wave voltage to the incident wave voltage at a point on the transmission line:

$$\Gamma = \frac{V^-}{V^+}$$

Radiation pattern. The radiation field characteristics of antenna can be expressed by image to form the antenna pattern, which can express the ability of antenna to receive and radiate electromagnetic waves in all directions. The functional relationship between antenna radiation field characteristics and space coordinates is called antenna directivity function. When r is constant, the radiation field of the antenna varies only with θ and ϕ. At this time, the expression of the field is normalized, which is more convenient to use. We select a cross section and divide the field value of each point by the maximum value of the cross section to obtain the normalized pattern.

$$F(\theta, \phi) = \frac{E}{E_{max}}$$

Gain. The antenna's directivity coefficient is based on the radiation power and does not consider the antenna's own loss, such as ohmic loss. In order to describe the antenna performance more comprehensively, another parameter, gain, is introduced. The gain of the antenna is defined as the ratio of the power density of the signal generated by the antenna to the ideal undirected radiation unit at the same point in space when the input power is equal. The gain of an isotropic antenna is usually chosen as the reference value and the gain in decibels is defined.

$$G_{dB} = 10\log G$$

2.2 Implementation method of frequency reconfigurable antenna

The first method is to realize frequency reconfiguration by switching tuning elements with radio frequency switches. The antenna uses radio frequency switch to switch different inductance values to achieve low frequency tuning, thus realizing full frequency operation. The second method is a reconfigurable mobile phone antenna based on resonant structure. This method uses PIN diode to control the change of branches, so that the antenna structure can work in monopole, loop or inverted F structure antenna respectively, and achieve different frequency band coverage. By controlling two PIN diodes on the antenna branch. The third method is to design a reconfigurable mobile phone antenna

IOP Conf. Series: Earth and Environmental Science **242** (2019) 022051 doi:10.1088/1755-1315/242/2/022051

with two antennas, which annotates the detailed structure of the antenna and the specific parameters of each part. The antenna consists of three parts: antenna radiation unit, control circuit and matching circuit. The antenna radiation element can be regarded as two inverted F antennas, and each antenna is fed by a coupled structure. The coupling feeding branch itself can produce resonance in the working frequency band, so this structure can widen the bandwidth. Energy saving of feeding branch can adjust the input impedance of antenna. By optimizing the parameters of feeding branch, the antenna can match well in each working frequency band.

2.3 Implementation method of polarization reconfigurable antenna
The most commonly used method to realize polarization reconfiguration is to use radio frequency switches as control devices, i.e. PIN diodes or MEMS radio frequency switches. At present, most of the papers published by researchers use PIN diodes or MEMS radio frequency switches to achieve polarization reconfiguration. Polarization reconfigurable antenna uses the structure of floor step slot to excite circular polarization wave. Two PIN diodes are connected at the two slots, which can control the switching-on independently, so that the antenna can work in two polarization states of LHCP and RHCP respectively. PIN diodes are cheaper, have faster response time, can carry more power, and require low on-voltage. RF MEMS has the advantages of low impedance, low parasitic capacitance and low insertion loss, so it is also widely used. The designed antenna is equipped with a MEMS RF switch at the two slots of the E-shaped structure to control its on-off to realize the change of polarization modes of LHCP and RHCP. The second method is to use the reconfigurable feeder network to switch the polarization reconfigurable. The unit antenna has two feeding ports. When the feeder network feeds the H Port separately, the antenna works in the horizontal polarization state; when the feeder network feeds the VPort separately, the antenna works in the vertical polarization state; when the feeder network feeds the H Port and V Ports simultaneously, When the phase lag of H Port is 90 degrees, the antenna works in the left circular polarization state; when the feed network feeds both H Port and V Port, and the phase of H Port is 90 degrees ahead of V Port, the antenna works in the right circular polarization state.

3. Development of frequency reconfigurable antenna

3.1 Development principles
With the development of mobile communication technology, especially the commercial use of 3G and 4G, and the application requirement of 5G communication in the future, the design of mobile phone antenna is facing many challenges, such as many bands, large panel, hard rear cover, small size, thousand disturbances and other practical problems. In order to deal with these problems, scholars at home and abroad have proposed a variety of solutions, such as broadband mobile phone antenna, multi-frequency mobile phone antenna and so on. As a viable alternative, frequency reconfigurable mobile phone antenna emerges as the times require. Frequency reconfigurable antenna can be regarded as narrow-band tenable antenna, which has both filter function and greatly reduces the filter requirements of the system. Therefore, the research of frequency reconfigurable mobile phone antenna has important application requirements.

3.2 Development process
We tune the low frequency by a single knife four throw switch. The antenna is set on a 140 x 70 mm substrate. The thickness is 0.8 mm. The material is FR4. It is fed by L-shaped branches and generates a high frequency resonance. Then it generates three resonances by feeding two bent grounding joints through coupling. The shorter branches are printed on the plane of L-shaped feeding joints to produce the second-high frequency resonance and the other one is relatively high frequency resonance. The long branch is connected in series with four inductors to produce a low-frequency resonance, and the low-frequency frequency reconfiguration is realized by switching the inductors in series to broaden the working frequency band. In addition, the coupling between the long grounding branch and the short

grounding branch generates a third high-frequency resonance. Therefore, each reconstructed state can produce four resonance frequencies, covering all the resonance frequencies as far as possible. Current mainly flows between the two grounding branches, but does not flow into the common ground. This shows that the second-high frequency resonance is mainly caused by the two branches, and the short grounding branches have greater impact. The three branches affect the third high frequency resonance. The second-high frequency resonance shifts to the low frequency and matches the wider band near the first high frequency resonance. The long grounding branch produces low frequency resonance, and the coupling between the longer grounding branch and the shorter grounding branch also has some influence on the high frequency. After the antenna is made, it is necessary to build an outfield and make a complete Frequency Reconfigurable antenna. Firstly, the matching positive pole of the power supply and the extension part of the feeding copper axis of the antenna are welded together with thin wires, and the voltage can be connected with the radiation patch and metal frame through the feeding copper axis. In this way, all upper copper surfaces of the antenna maintain the same high potential. Then, the thin wire connecting the negative pole of the power supply is welded on the ground plate of the antenna as zero potential. When the power supply is connected, the electric field is concentrated between the upper and lower electrodes, because the size of the upper and lower electrodes is the same. The electric field inside the antenna becomes a uniform electric field, and the film is uniformly polarized.

3.3 Experiment result

When the antenna works in state I, the impedance bandwidth of -6dB covers high frequency 1485MHz-2820MHz, and low frequency covers frequency 792MHz-960MHz; when the antenna works in state 2, it covers frequency 749MHz-793MHz; when the antenna works in state 3, it covers frequency 717MHz-760MHz. When the antenna works in state 4, it covers frequency 683MHz-720MHz Generally speaking, the antenna can cover low frequency and have complex polarization modes. Dipole antenna patterns show similar performance at low frequencies, and more lobes are generated at high frequencies. This is because the antenna wavelength is shorter at high frequencies, and the short side of antenna ground has greater impact on antenna radiation. For mobile antenna, such lobes are acceptable. The better omnidirectional antenna is, the more suitable for receiving signals in complex scenes. The measured gain and radiation efficiency of antenna are shown in Figure 1. Low-frequency gain is small, ranging from -2.4dBi to 2.5dBi. High-frequency gain is relatively stable. Radiation efficiency is greater than 45% at low frequency and 60% at high frequency. The overall radiation performance of the antenna is good.

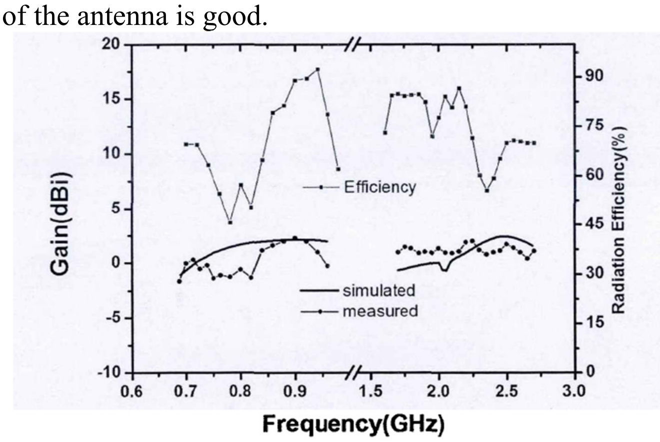

Figure 1. Gain and efficiency of frequency reconfigurable antenna

4. Development of polarization reconfigurable antenna

4.1 Development principles

With the development of communication technology, more and more attention has been paid to the polarized reconfigurable antenna. The application of polarized reconfigurable antenna in wireless communication has certain advantages. The planar antenna fed by coplanar waveguide has a very advantageous feature, that is, its radiation unit and feed unit are in the same plane. The advantage of this method is that it is easy to integrate with active devices, while the reconfigurable antenna needs to be integrated. Using RF MEMS or PIN diodes as active control devices to achieve reconfigurable function, coplanar waveguide antenna is very suitable for reconfigurable antenna design. Three methods are single-feed method with perturbation structure, multi-feed method with increasing feed excitation and multi-feed method with rotating structure. Although single-feed method is simple, easy to realize and has smaller size, its bandwidth is relatively narrow and its polarization performance is relatively poor. Multi-feed method is one of the methods to expand bandwidth. It mainly uses multiple feed points to microstrip patch antenna or multi-arm. The helical antenna is fed by four feeding points with equal amplitude and orthogonal phase difference of 90 degrees. The better the performance of the feeding network, the better the working conditions of circular polarization can be guaranteed. The circular polarization bandwidth obtained by this structure can often be comparable to the impedance bandwidth. The multi-feed method is divided into double-fed and four-fed, in which the doubly-fed microstrip antenna is fed by two equal-amplitude orthogonal signals from power divider or bridge. In order to achieve circular polarization, two orthogonal working modes are excited. Four-feed method is that four feeding points are fed by four signals.

4.2 Development process

The centre frequency of the antenna design is 2.45 GHz. When the phase difference of the electric field vector is 90 degrees, the electric field vector on the four-leaf clover structure is orthogonal, indicating that the antenna excites two orthogonal electromagnetic wave modes, thus forming circular polarization. The radiation wave PIN diode is SMPA1320-079LF. It has the characteristics of low parasitic resistance and low parasitic capacitance. Its working frequency range is from 10 MHz to 10 GHz. It can be equivalent to 0.75Q resistance when conducting, and it can be equivalent to 0.23pF isolation capacitance when closing. We use high frequency capacitance to isolate DC signal, high frequency inductance to isolate RF signal, DC port can feed DC positive voltage and DC port. The DC negative voltage is used to control the on-off of PIN diode and the suspended floor in the middle layer, so that the coplanar waveguide antenna with two-sided radiation can realize unidirectional radiation. The third layer is a reflector plate structure. The copper sheet with FR4 dielectric plate structure is used to place the radiation patch h+hl+h2 at the distance, which further reduces the backward radiation and improves the forward gain under the condition that the phase difference of electric field is 90 degrees. The trajectory of the electric field vector of the antenna radiation is close to a clockwise circle, which indicates that the antenna excites two orthogonal electromagnetic wave modes, thus forming a left-handed circularly polarized radiation wave. Starting with the concept of polarization, the design principle is introduced to determine the antenna model. The final size of the antenna is optimized by step-by-step simulation, and the polarization modes of the antenna are checked. Good polarization reconfiguration performance is achieved. The simulation results also meet the design requirements.

4.3 Experiment result

The antenna design first determines the basic structure, then uses Ansoft's HFSS to simulate. Finally, the antenna object is made. By controlling the switching state of PIN diode, the antenna can realize the conversion of LHCP and RHCP. In both polarization states, the antenna can work in 2.45GHz band. When PIN diodes 1 and 3 are on, the antenna works in RHCP state. When PIN diodes 2 and 4 are on, the antenna works in LH state. CP state Measured antenna reflection coefficient SI. The measured-10dB impedance bandwidth is 300MHz (2.28-2.58GHz). The measured data are basically in agreement with the simulation results. Axis ratio is an important index to measure the circular polarization performance. Generally, the Axis ratio below 3dB can be considered as the radiation pattern under two polarization states. Because of the antenna structure of coplanar waveguide, the antenna is bidirectional radiation. According to Friis formula, the gain of the antenna to be measured can be calculated. Figure 2 shows that the measured and simulated antenna gain are basically in agreement with the simulation results near the central frequency. In the whole frequency band, the measured gain is greater than 2dBi. Compared with the simulated gain, the fluctuation indicates that the measured maximum gain is 3.89dBi.

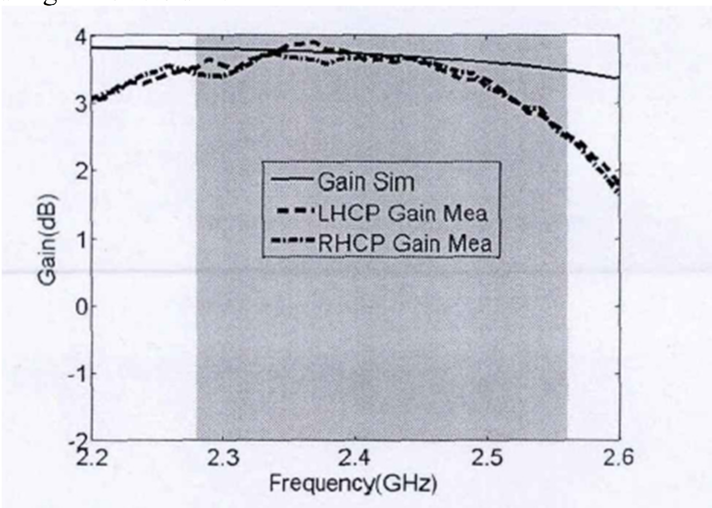

Figure 2. Results of simulated gain and measured gain of polarization reconfigurable antenna

5. Conclusions

The main object of this paper is the frequency reconfigurable antenna and polarization reconfigurable antenna. The main conclusions are as follows:

(1) The purpose and significance of frequency and polarization reconfigurable antenna are discussed, and the realization methods of frequency and polarization reconfigurable antenna are given based on related theory.

(2) A frequency reconfigurable antenna using radio frequency switch is developed. The antenna uses a monopole coupled feed structure to cover all the WWAN and LTE bands in the 4G era.

(3) A polarization reconfigurable antenna fed by coplanar waveguide is developed, which can realize switching function between left-handed circular polarization and right-handed circular polarization.

References

[1] Zhu H L, Cheung S W, Liu X H, et al. Design of polarization reconfigurable antenna using metasurface [J]. IEEE Trans. Antennas Propag., 2014, 62(6): 2891-2898.
[2] Lin W, Wong H. Wideband circular polarization reconfigurable antenna[J]. IEEE Transactions on Antennas and Propagation, 2015, 63(12): 5938-5944.
[3] Lin W, Wong H. Wideband circular-polarization reconfigurable antenna with L-shaped feeding probes[J]. IEEE Antennas and Wireless Propagation Letters, 2017, 16: 2114-2117.
[4] Rodrigo D, Cetiner B A. Frequency, radiation pattern and polarization reconfigurable antenna using a parasitic pixel layer[J]. IEEE transactions on antennas and propagation, 2014, 62(6): 3422-3427.
[5] Kandasamy K, Majumder B, Mukherjee J, et al. Low-RCS and polarization-reconfigurable antenna using cross-slot-based metasurface[J]. IEEE Antennas and Wireless Propagation Letters, 2015, 14: 1638-1641.
[6] Row J S, Tsai C W. Pattern reconfigurable antenna array with circular polarization[J]. IEEE Transactions on Antennas and Propagation, 2016, 64(4): 1525-1530.

[7] Osman M N, Rahim M K A, Hamid M R, et al. Compact dual-port polarization-reconfigurable antenna with high isolations for MIMO application[J]. IEEE Antennas and Wireless Propagation Letters, 2016, 15: 456-459.
[8] Row J S, Wei Y H. Wideband Reconfigurable Crossed-Dipole Antenna With Quad-Polarization Diversity[J]. IEEE Transactions on Antennas and Propagation, 2018, 66(4): 2090-2094.
[9] Di Palma L, Clemente A, Dussopt L, et al. Circularly-polarized reconfigurable transmitarray in Ka-band with beam scanning and polarization switching capabilities[J]. IEEE Transactions on Antennas and Propagation, 2017, 65(2): 529-540.
[10] Lin W, Wong H. Polarization reconfigurable wheel-shaped antenna with conical-beam radiation pattern[J]. IEEE Transactions on Antennas and Propagation, 2015, 63(2): 491-499.
[11]Lin W, Wong H. Multipolarization-reconfigurable circular patch antenna with L-shaped probes[J]. IEEE Antennas and Wireless Propagation Letters, 2017, 16: 1549-1552.
[12] Lee S W, Sung Y J. Simple polarization-reconfigurable antenna with T-shaped feed[J]. IEEE Antennas Wireless Propag. Lett, 2016, 15: 114-117.
[13] Wang R, Wang B Z, Gao G F, et al. Low-Profile Pattern-Reconfigurable Vertically Polarized Endfire Antenna With Magnetic-Current Radiators[J]. IEEE Antennas and Wireless Propagation Letters, 2018, 17(5): 829-832.
[14] Cao Y, Cheung S W, Yuk T I. A simple planar polarization reconfigurable monopole antenna for GNSS/PCS[J]. IEEE Transactions on Antennas and Propagation, 2015, 63(2): 500-507.
[15] Ni C, Chen M S, Zhang Z X, et al. Design of Frequency-and Polarization-Reconfigurable Antenna Based on the Polarization Conversion Metasurface[J]. IEEE Antennas and Wireless Propagation Letters, 2018, 17(1): 78-81.
[16] Yang Y, Simorangkir R B V B, Zhu X, et al. A novel boresight and conical pattern reconfigurable antenna with the diversity of 360 polarization scanning[J]. IEEE Transactions on Antennas and Propagation, 2017, 65(11): 5747-5756.