Design and simulation of pattern reconfigurable antenna based on RF-MEMS

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Abstract：The reconfigurable antenna based on RF-MEMS is hot researching direction in recent years,it can change electric parameters,such as radiation pattern,working band, input impedance, polarization diversity ,and so on. reconfigurable antenna of multi-band and multi-mode can replace multiple antennas based on one vehicle,decreases the developing price,size and weight of antennas,which is very important to the satellite communication and wireless communication. This paper presents the design of a broadband and wide-angle pattern reconfigurable antenna. The antenna is composed of four different linear phased arrays, in which the element is designed with different phase shift. The pattern of the whole antenna can be changed by six RF-MEMS switches, which are placed in the feed network. The feed network uses a novel compact broadband impedance transformer, and the microstrip slot antenna acts as an antenna element. The VSWR(Voltage Standing-Wave Ratio) of the antenna element in a broadband from 2.4 GHz to 3.4 GHz is less than 2. The simulation result demonstrates that the reconfigurable antenna realizes different patterns(0°,25°,40°and 50°) in different RF-MEMS switching states, furthermore, theVSWR of the reconfigurable antenna under each of these four different states is less than 2 from 2.5 GHz to 3.25 GHz except for part frequency points.The paper has important value to the design of beam scanning of phased array antenna in satellite communication.

Key words：RF-MEMS switch,reconfigurable antenna,microstrip slot antenna,broadband impedance transformation.

I. Introduction

WITH high speed development of modern satellite commuunication and wireless communication,especially with arising of MIMO system,information increases sharply within one vehicle,the communicating bandwidth is larger and larger,the demanding performance for antenna is higher and higher.If the traditional antennas are adopted,multiple antennas must be installed within one vehicle,so as to transmit and receive different signals.With regard to the space vehicle,the whole design cost,weight and size will increase greatly,some problems ,such as coupling among different antennas and electromagnetic compatibility, will impact on the system performance,the concept of “reconfigurable antenna” is proposed.It can change the electrical structure within one antenna in real time,the radiation characteristic is changed accordingly. The reconfigurable antennas contain defferent types:frequency reconfigurable,radiation pattern reconfigurable, frequency and pattern reconfigurable,polarization reconfigurable,and so on.[1,2]

In recent years,with development of MEMS technology,especially developing of MEMS switches of high performance and low power cost,reseach on the reconfigurable antennas is deepened, technology concerned with the reconfigurable antennas is studyed by scholars at home and abroad. [3-6]MEMS switches have much excellent radio frequency performance,such as small size, low conducting insertion loss within broad bandwidth,high disconnecting isolation and low parasitic capacitance.

The reconfigurable antenna based on RF-MEMS can change electric parameters easily ,such as radiation pattern,working band, input impedance, polarization diversity ,and so on. reconfigurable antenna of multi-band and multi-mode can replace multiple antennas based on one vehicle,decreases the developing cost,space and weight of

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antenna,which is very important to the satellite communication and wireless communication. This paper presents the design of a broadband and wide-angle pattern reconfigurable antenna,the performance is verified by simulation.

II. Design Thought and Realization of the Reconfigurable Antenna

A. Design Thought

Different beam direction or the same physical aperture shared by multiple frequency can be achieved by the reconfigurable antenna ,by controlling the on/off state of feed within every element of phased array antenna,or changing the state of switches installed in some specified position.The pattern reconfigurable antenna designed in this paper is presented in Fig. 1,the phased array contains four subarrays with different beam direction,each subarray has four elements, different beam direction can be achieved by controlling the on/off state of six RF-MEMS switches.if No.1 and No.5 switches are on, No.2,No.3, No.4,and No.6 switches are off,the first subarray can radiate power, if No.2 and No.5 switches are on, No.1,No.3, No.4,and No.6 switches are off,the second subarray can radiate power, if No.3 and No.6 switches are on, No.1,No.2, No.4,and No.5 switches are off,the third subarray can radiate power, if No.4 and No.6 switches are on, No.1,No.2, No.3,and No.5 switches are off,the fourth subarray can radiate power.

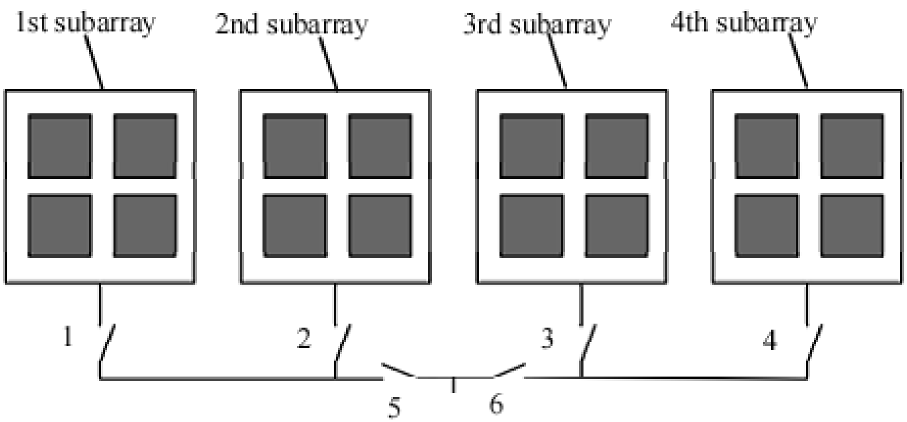


Figure 1. Schematic of pattern-reconfigurable antenna

B. Design of Antenna Element

The microstrip slot antenna is adopted by the antenna element[7],the structure is presentd in Fig. 2,the media substrate is Rogers RT5880,the thickness is 0.5mm, the dielectric constant is 2.2, the slot structure with back etching media substrate is adopted by the radiating element,the slot shape is like H,which can decrease the size,wide bandwidth can be achieved.

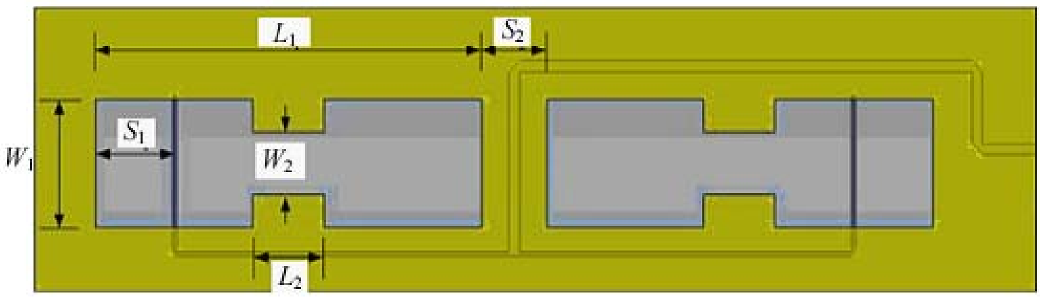


Figure 2. Schematic of antenna element

The slot antenna can be feeded by microstrip feed line whose impedance is 100Ω,it can be combined with the transfering line whose impedance is 50Ω,so the broad bandwidth performance can be matched.The specific size of antenna is: W1=18mm,W2=9mm， L1 =54 mm, L2=10 mm， S1=11mm， S2 =9mm.

The VSWR(Voltage Standing-Wave Ratio) simulation result is presented in Fig. 3,from fig.3,VSWR is less than 2 in the range of 2.4GHz to 3.4GHz,the relative bandwidth is 34.5%.The simulation result of radiation pattern of antenna element is presented in Fig. 4,the frequency is 2.8GHz,the gain is high ,which is 9.2dB.

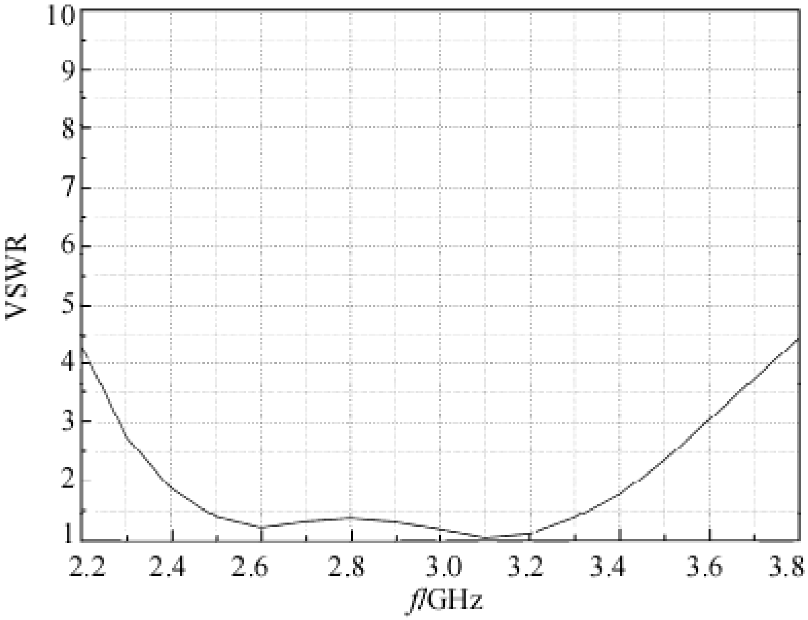


Figure 3. Simulation VSWR of antenna element

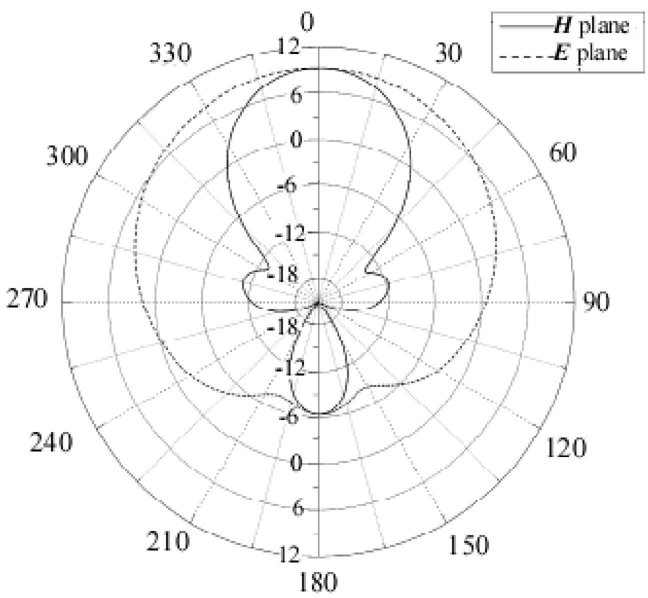


Figure 4. Simulation pattern of antenna element

C. Design of Feed

The different beams are formed by 4 antenna subarrays,the power dividers and phasers are used, to achieve the small size of feed, matching method of broad bandwidth impedance is used by the power dividers[8],it has smaller size,broader bandwidth.compared with using 1/4 impedance transformer,the phase shifting is achieved by microstrip lines of different length,the length of transmitting line is determined by Eq. (1). The impedance of transmitting line is changed from Z_L=100Ω to Z_0=50Ω by this method.The structure is presented in Fig. 5, Z_0 is input impedance,which is 50Ω, Z_L is output impedance,which is 100Ω,the power divider is presented in Fig. 6, referring to the design of broad bandwidth impedance transformer.

$$\begin{cases} l_1 = \frac{1}{2}\arcsin\left(\frac{\rho_2}{\rho_1}\sin(\beta_1)\right) \\ l_2 = \frac{1}{2}[\pi - \beta_1] \\ l_3 = \frac{1}{2}\arcsin\left(\frac{\rho_1}{\rho_2}\sin(\beta_3)\right) \\ l_4 = \frac{1}{2}[\pi - \beta_3] \end{cases} \qquad \begin{cases} \beta_1 = \arccos\left(-\frac{\rho_2}{2\rho_1}\right) \\ \beta_3 = \arccos\left(\frac{\rho_2^2 - 2\rho_1^2}{2\rho_1^2}\right) \\ \rho_1 = \frac{Z_L - Z_0}{Z_0 + Z_L} \\ \rho_2 = \frac{1}{2}\rho_1 \end{cases} \tag{1}$$

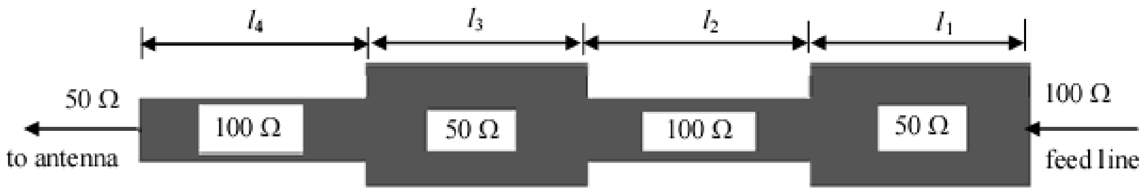


Figure 5. Transmission line transformer

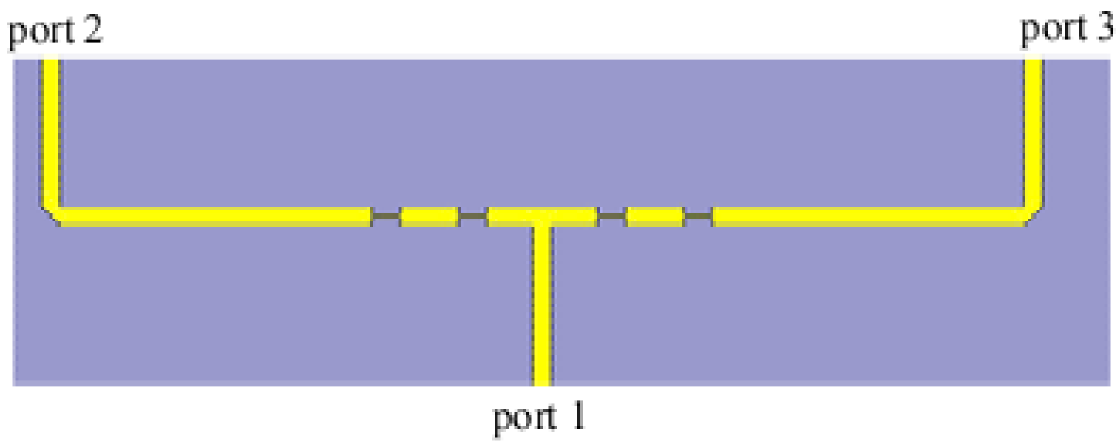


Figure 6. Power divider with transformer

The simulation result of power divider is presented in Fig. 7, the size is optimized by HFSS software,the return loss of every port is less than -14dB,the insertion loss is less than 0.2dB, which is presented in Fig. 8.

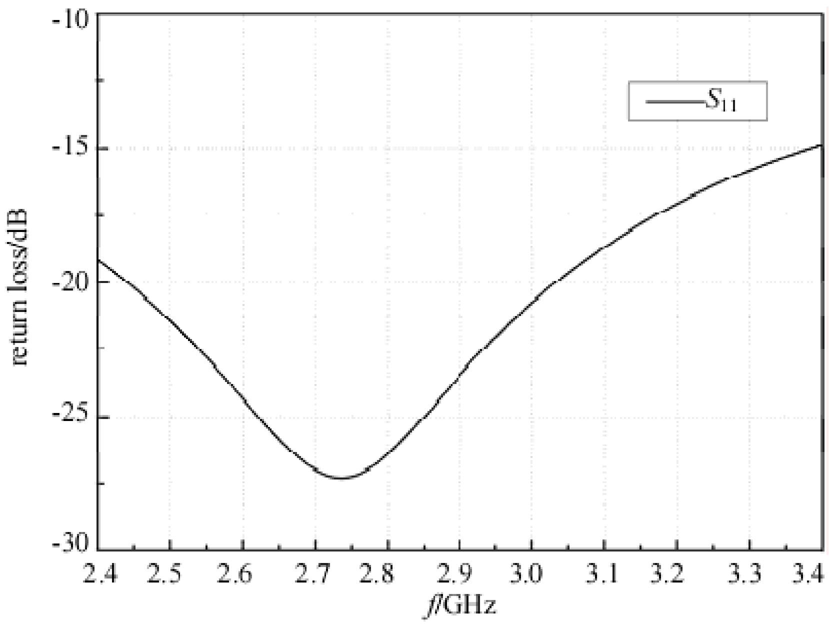


Figure 7. Simulation return loss of power divider

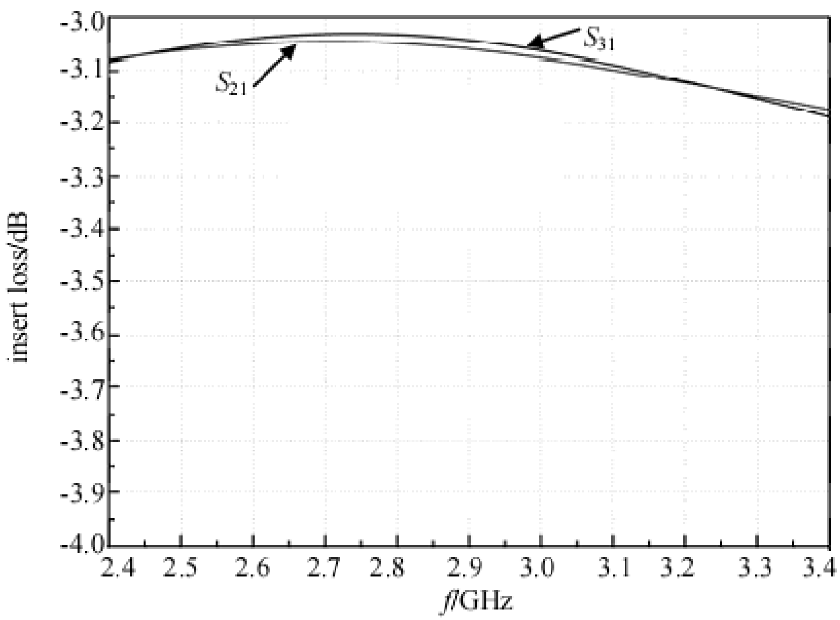


Figure 8. Simulation insertion loss of power divider

D. Installation of MEMS Switch

The MEMS switch is DC contacting CPW MEMS switch in series.[9]The switch isolation is determined by capacitance Cu of “UP” state,which is presented in Eq. (2),when Cu=2 fF,the isolation is presented in Fig. 9,the switch has good isolation in the range of working frequency of antenna.

The insertion loss of “DOWN” state is determined by contacting resistance of Rs and inductance of L,when ω L«Rs,the insertion loss is presented in Eq. (3).

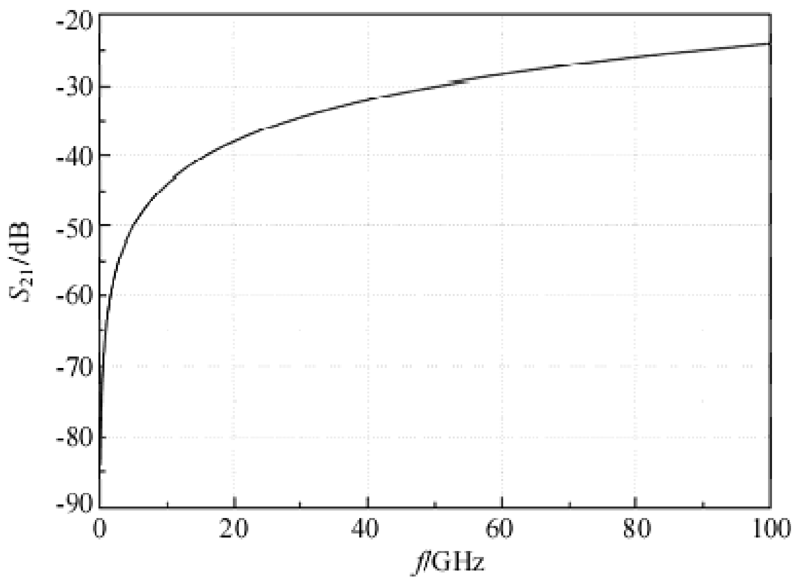


Figure 9. Isolation of RF-MEMS switch

When Rs=1Ω~2Ω,the insertion loss is -0.1dB~-0.2dB.because the RF-MEMS switch has excellent radio frequency performance,the “on” state of RF-MEMS switch can be replaced by rectangle metal patch in the simulation, the “off” state of RF-MEMS switch can be simulated when the rectangle metal patch is not contained.The width of the rectangle metal patch is 0.2mm, the RF-MEMS switch and the installation position is presented in Fig. 10, the RF-MEMS switch is installed in the circling position,the CPW GND is connected to the patch of both ends,the patch is connected to the back GND board by metal hole,the radio frequency line is connected to the microstrip by gold line.

$$S_{21} = \frac{2j\omega C_u Z_0}{1 + 2j\omega C_u Z_0} \quad (2)$$

$$S_{21} = 1 - \frac{R_s}{2Z_0} \quad (3)$$

In the simulation,the installation way of MEMS switch and its effect concern much factor,to simplify the simulation computing,the performance of conducting microstrip and the patch connected to GND is simulated,which is related to the on/off state of switch,the whole encapsulation performance is not simulated.

All parts are combined in the reconfigurable antenna,the structure figure is presented in Fig. 11.The feeds are in front of antenna ,which consist of microstrip feed lines,power dividers,phasers,MEMS switches, the radiating elements are in the back,4 antennas form 1 group,the sum is 4 groups.The filters which adopt EBG(Electromagnetic-Bandgap) structures are under the radiating elements.The board connected to GND of EBG and antenna array are connected directly,the DC power supplying lines are connected to MEMS switches by metal hole,when “on/off” state of MEMS switches is changed, the different beam direction is formed.

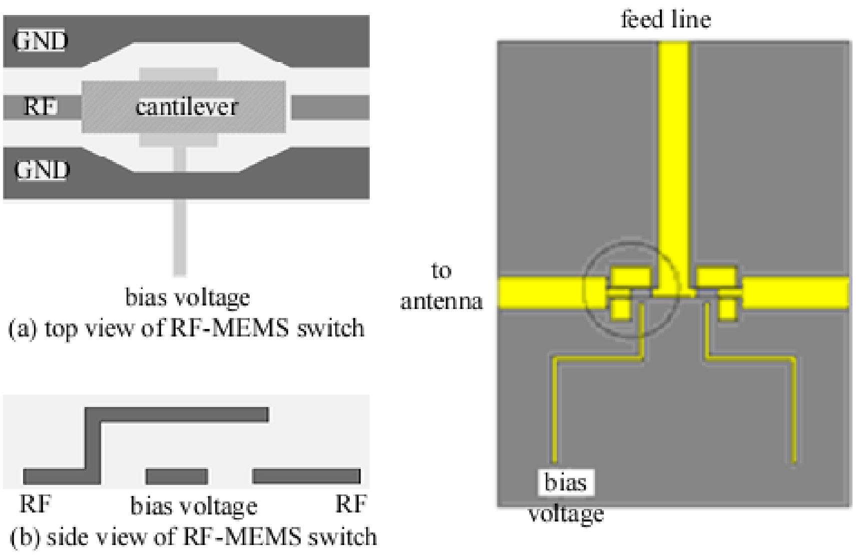
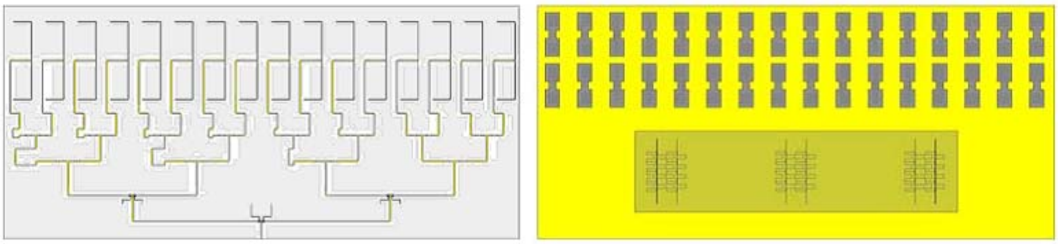


Figure 10. Schematic of RF-MEMS switch and connecting point on substrate



(a) top view of antenna **(b) bottom view of antenna**

Figure 11. Schematic of pattern-reconfigurable antenna

III. Simulation Results

The simulation model of antenna is builded by HFSS software,the antenna array has 4 state.The first state is:switch 1 and 5 are on,the other are off,the first subarray radiates power,the phase of every element is same,the beam direction is 0°. The second state is:switch 2 and 5 are on,the other are off,the second subarray radiates power,the phase difference is 30°between neighbour element,the beam direction is 25°. The third state is:switch 3 and 6 are on,the other are off,the third subarray radiates power,the phase difference is 60°between neighbour element,the beam direction is 40°. The fourth state is:switch 4 and 6 are on,the other are off,the fourth subarray radiates power,the phase difference is 90° between neighbour element,the beam direction is 50°.

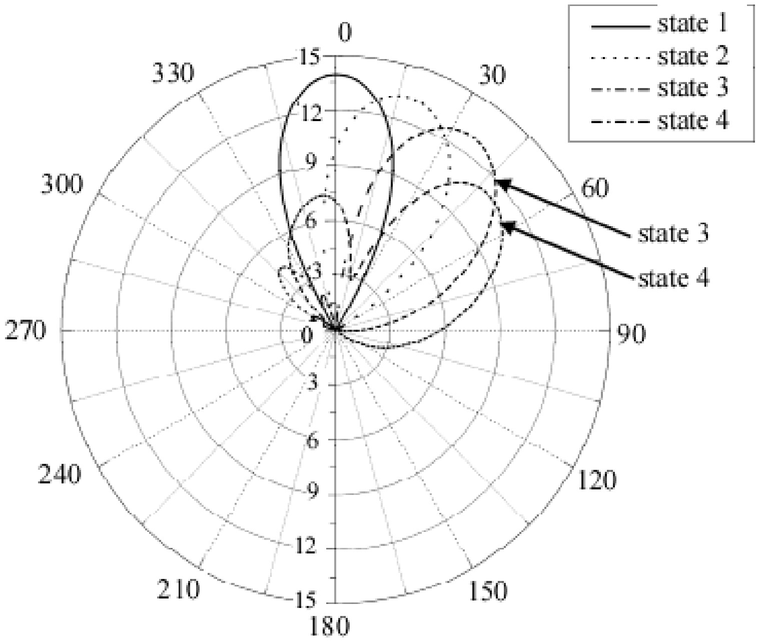


Figure 12. Simulation pattern of four different states

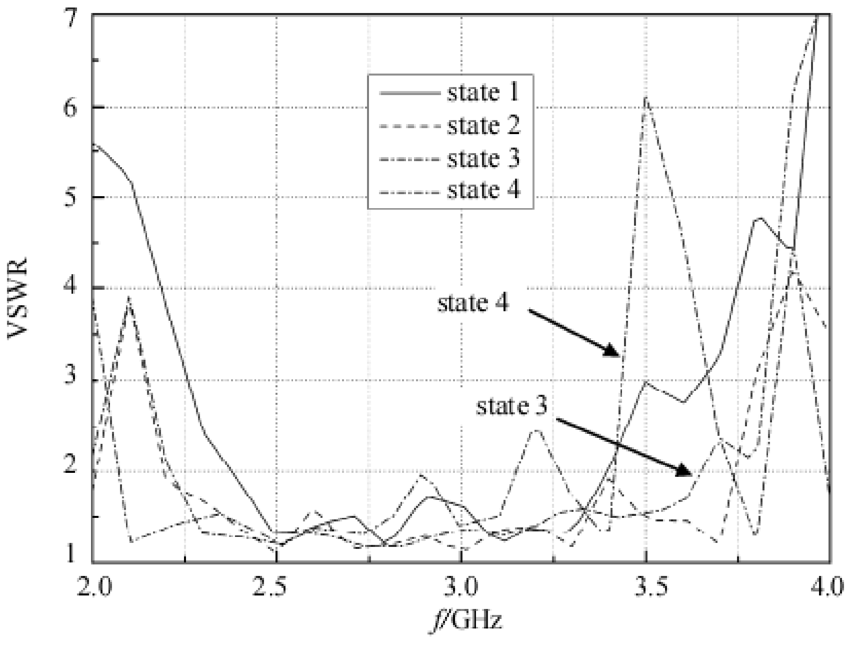


Figure 13. Simulation VSWR of four different states

In the simulation,the "on/off" state of switches is simulated by connecting or disconnecting of the metal patch.The simulation results are presented in Fig. 12,VSWR simulation results are presented in Fig. 13. The pattern reconfigurable antenna and broad bandwidth matching are achieved.

IV. Conclusion

A pattern reconfigurable antenna is designed,which is simulated by HFSS software,itsperformance is testified by the simulation results, 0°,25°,40°and 50°beam direction can be achieved by the antenna, VSWR under each of these four different states is less than 2 from 2.5 GHz to 3.25 GHz except for part frequency points.The paper has important value to the design of beam scanning of phased array antenna in satellite communication.

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