A Pattern Reconfigurable Microstrip Patch Antenna With Through Glass Via

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***Abstract*—In this paper, a pattern reconfigurable microstrip patch antenna with through glass via (TGV) by loading parasitic patches is proposed. It consists of a driving microstrip patch antenna and a pair of parasitic patches symmetrically placed on both sides of the driving patch antenna. A PIN diode is loaded on the parasitic patch as a switch by changing the voltage applied to the PIN diode, thus realising three parasitic patch states. The antenna adopts an advanced through glass via (TGV) process, which greatly improves the accuracy and reduces the loss compared with PCB. The centre frequency of the antenna is set at 33 GHz during the simulation. The proposed antenna can be miniaturised with a size of $0.44\lambda_0 \times 0.44\lambda_0 \times 0.09\lambda_0$, with a bandwidth of 10.8% in the 29.9−33.3 GHz band, and a peak gain of more than 6.1 dBi for all three states. With the merits of low profile, miniaturisation, and advanced TGV techniques, the proposed antenna is suitable for future heterogeneous integration applications.**

Keywords—microstrip patch antenna, millimeter wave (MMW), through glass via (TGV), pattern reconfigurable antenna

I. INTRODUCTION

To meet the requirements for higher data rates and lower latency, millimetre-wave (mm-wave) frequencies have been adopted for fifth-generation (5G) mobile communication systems [1], [2]. However, millimetre-wave has higher free-space losses than lower frequency bands. To mitigate the path loss, 5G millimetre-wave systems usually use high-gain antennas with beam steering characteristics [3]. Furthermore, for mobile terminals, mobile antennas should only take up a small amount of space as most of the space is reserved for the display, camera, battery, PCB, etc [4], [5]. In addition, the cost should be as low as possible considering the mass production of consumer electronics. Therefore, for mobile terminals, it is preferable to design a low-cost beam steering mm-wave antenna within a compact space. In this paper, we present a reconfigurable millimeter-wave antenna cell that achieves satisfactory beam-steering performance through the use of a limited number of PIN diodes and a planar-integrated design approach.

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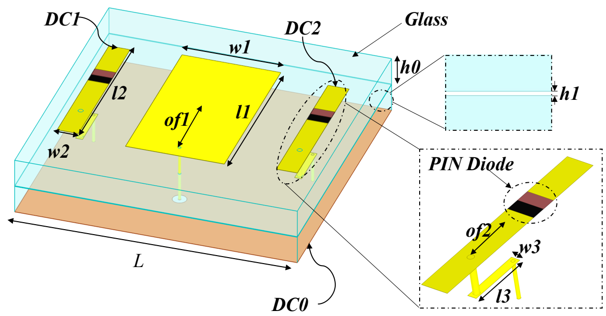


Fig. 1. Geometry of the proposed antenna.

TABLE I. SPECIFIC PARAMETERS OF THE ANTENNA(UNIT:mm)

Parameter	*l*	*l1*	*w1*	*of1*	*l2*
Value	4.0	2.4	1.4	1.0	2.2
Parameter	*of2*	*l3*	*w3*	*h0*	*h1*
Value	0.55	0.66	0.1	0.4	0.01

II. ANTENNA CONFIGURATION

The structure of the antenna is shown in Fig. 1, it is divided into upper and lower layers, and the dielectric material of both layers is glass, the height of the two glasses is the same, and the upper surface of the upper layer of glass is printed with the main radiating patch and the parasitic patches on both sides, in which the parasitic patches are connected with PIN diodes, and two symmetrical and small conversion wires are printed on the lower surface of the upper layer of glass, which are connected to the parasitic patches on the upper surface by the TGV. The lower surface of the lower glass is all printed with metal as the ground plane, a circular hole acts as the input port of the coaxial cable, and the parasitic patch is connected to the ground plane by the metallized TGV and small conversion wires, as well as by planting ball welding to provide a direct current path for the PIN, and at the same time there is enough path length to play the role of an open circuit for RF signals, between the two layers of glass, there is a very thin layer of the air layer, this is to consider the welding between the two layers of glass will leave a fine air layer, the specific parameters of the antenna are shown in Table 1.

III. Antenna Principle

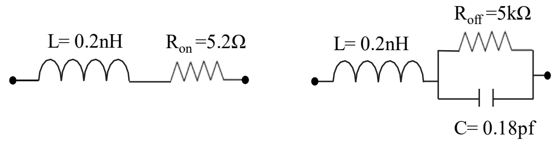
In this chapter, the DC voltage is added to the PIN diode to control its ON/OFF, thus changing the surface current of the parasitic patch, when all switches are turned on, the antenna is in a mismatched state, which will not be discussed subsequently, when both sides of the switch are OFF, the antenna is operating in state 0, and both sides of the parasitic patch on the current state is the same, the formation of the forward radiation. When the switch on one side is open, the current on its parasitic patch lags the current on the main radiating patch, thus acting as a diverter. In contrast, when the switch on the other side is closed, the current on its parasitic patch overruns the current on the main radiating patch, thus acting as a reflector. By changing the phase of the current on the parasitic patch, the radiation direction of the antenna changes, so that the radiation direction of the antenna is shifted to the side where the switch on the parasitic patch is open and the switch on the other side is closed, then there are two antenna states: state 1 and state 2. Therefore, by controlling the state of the PIN diode, three different radiation patterns can be achieved. The equivalent circuit diagram of the switch is illustrated in Fig 2. When the switch is closed, it is equivalent to a series connection of inductance with a value of 0.2nH and an ON resistance of 5.2Ω. When the switch is open, it is equivalent to a parallel connection of an OFF resistance of 5kΩ and a capacitance of 0.018pF, which is then series-connected with an inductance of 0.2nH. These equivalent lumped inductance, capacitance, and resistance values are represented at the location of the PIN diode in Fig 1.

IV. Results and Discussion

The S-parameters and gain curves of the antenna working in three states are obtained by simulation with HFSS software, as shown in Fig. 3, and the common impedance bandwidth of the three states is 3.4 GHz (29.9-33.3 GHz), and the relative fractional percentage bandwidth is 10.8%. When the antenna operates in state 0, its peak gain is 6.6 dBi in the frequency bandwidth of 29.9-33.3 GHz, When the antenna is operated in states 1 and 2, the peak gain is 5.7 dBi in the frequency bandwidth of 29.9-33.3 GHz. The radiation direction diagram of the antenna operating in state 1 is shown in Fig. 4(a). The same as analysed is the forward radiation pattern, the radiation direction diagrams of the antenna operating in states 1 and 2 are shown in Fig. 4(b), it can be seen that the antenna has an H-plane deflection angle of ±42° at 33 GHz, so the large deflection angle allows it to be used as an antenna cell for millimetre-wave reconfigurable arrays.

V. Conclusion

A millimetre-wave pattern reconfigurable antenna with TGV is designed and investigated in this paper. A PIN diode is loaded on the parasitic patch as a switch, it changes the radiation pattern of the antenna. The antenna employs an advanced TGV process, which greatly improves the accuracy and reduces the loss compared to the PCB process. Due to the low profile and the characteristics of miniaturization and the TGV technique, the antenna is promising for future heterogeneous integration technology.



(a) (b)

Fig. 2. Equivalent circuit of a PIN diode. (a) PIN diode ON state. (b) PIN diode OFF state.

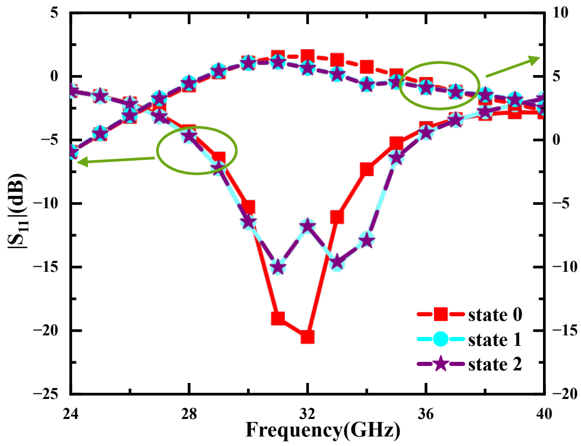
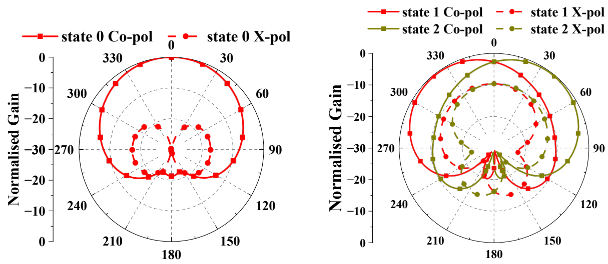


Fig. 3. S-parameter and gain simulation curves for three states of the antenna.



(a) (b)

Fig. 4. H-plane radiation pattern at 33 GHz. (a) Switches are all closed. (b) One side of the switch is open and one side is closed.

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