A Pattern Reconfigurable SIW Horn Antenna Realized by PIN Diode Switches

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***Abstract*—A novel pattern reconfigurable substrate integrated waveguide (SIW) horn antenna is presented in this paper. By embedding copper posts with ring slots in the middle of SIW and adding PIN diodes as tuning switches, the operating states of the SIW can be electronically controlled. Six SIW H-plane horn antennas are sequentially placed on a circular substrate. Accordingly, the radiation direction of the proposed antenna can be switched by tuning the states of SIW switches, and a 360° beam-steering reconfigurable ability is obtained. Moreover, a printed lens is introduced between the horn aperture and free space for achieving a high gain and good directional radiation patterns. Simulated results illustrate that the proposed antenna is capable of switching the end-fire beam with six identical radiation patterns in the H-plane. Meanwhile, a peak gain improvement around 6 dBi is achieved by employing the printed lens.**

***Index Terms*—H-plane horn antenna, PIN diode, pattern reconfigurable antenna, substrate integrated waveguide (SIW).**

I. Introduction

Reconfigurable antennas have great potential in achieving multifunction antennas for advanced wireless communication systems. Their radiation pattern, operating frequency or polarization can be tuned without changing the antenna structure. Generally, by using the electromechanical or electrical switches, such as the RF microelectromechanical systems (MEMS) [1]–[3], varactors [4], p-i-n (PIN) diodes [5], [6], liquid crystals [6], or water [7], the reconfigurable antennas can be obtained. Comparing to the varactor diodes and the MEMS switches, the PIN diodes have low cost and smallest switching states, i.e. "on" and "off" states. Meanwhile, PIN diodes are very suitable for the integrated applications.

Substrate integrated waveguide (SIW) is an emerging integrated planar transmission line. For many applications, such as satellite communications, remote sensing, and cellular base stations, high-performance beam-steering SIW antennas are of increasing interest. Using phased array antennas or SIW leaky-wave antennas is a conventional approach to realize a beam-steering ability. However, the feed network of phased array antennas is too expensive and beam-scanning of leaky-wave antennas is achieved by frequency sweep [8], [9]. By using pattern reconfigurable antennas, the beam-steering ability can also be achieved electronically. SIW based horn antenna provides advantages, such as low profile, low cost, and good end-fire directional radiation pattern [10]. The beam-steering ability can be obtained by the pattern reconfigurable SIW horn antennas, while the directional radiation patterns keep stable over the entire operating frequency band. In [11], a 360° beam-steering reconfigurable SIW horn antenna was developed. The beam-switchable function was achieved by changing the states of the PIN diodes. However, the number of used PIN diodes was too large (64 switches) and the structure was complicated.

In this paper, a pattern reconfigurable SIW horn antenna realized by 12 PIN diodes is proposed. By embedding a copper post with a pair of ring slot and two PIN diodes in the middle of SIW, a SIW switch is obtained. Using the SIW switches as tuning switches, the exciting states of SIW horn antenna can be electronically controlled. Six SIW H-plane horn antennas are constructed in a single-layer circular substrate. Then, the radiation direction of the proposed antenna is switched by tuning the states of SIW switches. Accordingly, a 360° beam-steering reconfigurable ability is obtained. Moreover, the conventional H-plane SIW horn printed on thin substrates features poor radiation performance. To solve this issue, a printed lens is placed in front of the horn aperture to further improve the antenna gain and achieve a good directional radiation pattern. From the simulated results, the proposed antenna can switch the end-fire beam with six identical radiation patterns in the H-plane. Meanwhile, a high gain is also achieved by employing the printed lens.

II. Antenna Design and Operating Principle

A. Antenna Geometry

Fig. 1 shows the proposed pattern reconfigurable SIW horn antenna. Six SIW H-plane horn antennas are sequentially placed on a circular substrate. The antenna is fed by a coaxial probe with a radius of 0.15 mm and a height of 1.524 mm. To tune the states of the SIW horn, six SIW switches is utilized. As shown, each SIW switch includes a copper post with a pair of ring slots etched on both layer of SIW and two PIN diodes on the top layer of SIW. It means that there are 6 copper posts, 12 ring slots, and 12 PIN diodes altogether.

An extended printed lens, sharing the same substrate with the proposed antenna, is placed in front of the horn aperture. The proposed antenna is constructed on a 1.524 mm thick Rogers RO4003C substrate with a permittivity of 3.55. The width of the SIW (a) is 4.8 mm, ensuring a single mode (TE_{10}) excitation of the horn. The horn flaring length (l_1) is 20.2 mm, and the aperture width of each horn (w_1) is 18.1 mm.

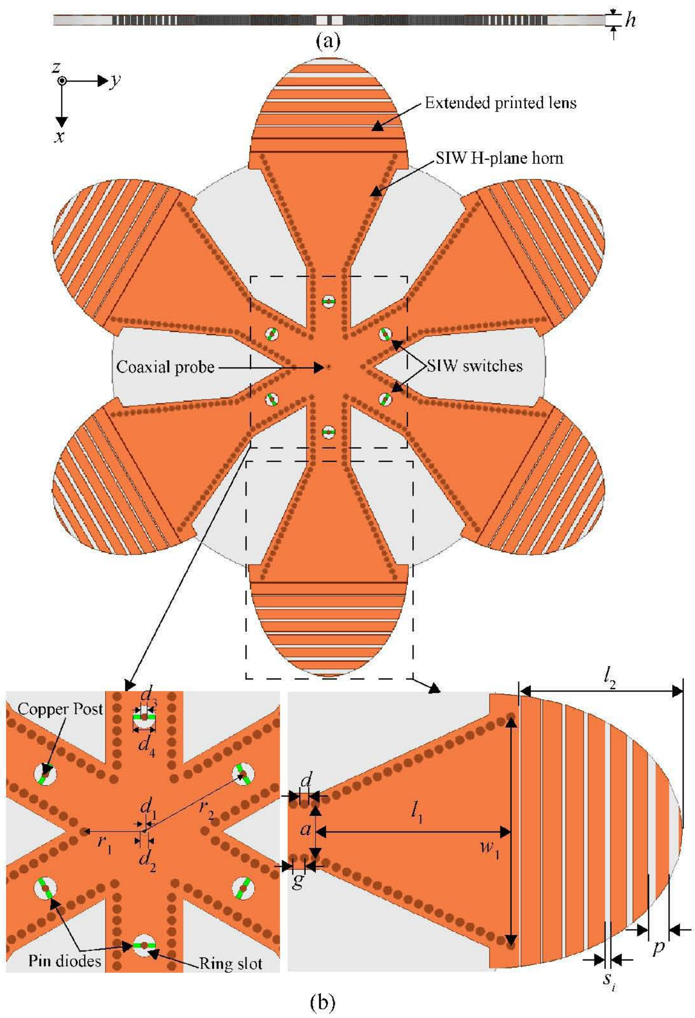

Fig. 1. Geometry of the proposed reconfigurable antenna. (a) side view, (b) top view.

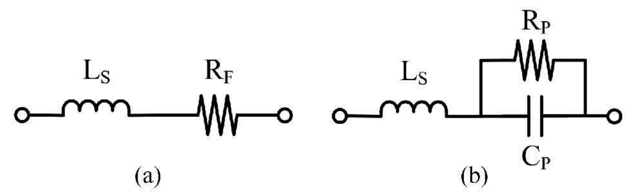

Fig. 2. Equivalent circuits of the PIN diode. (a) ON state. (b) OFF state. (L_S = 0.5 nH, R_F = 4 Ω, C_P = 0.025 pF, R_P = 10 kΩ)

Fig. 3 shows the simulated S-parameters of the SIW switch at different states. Because a large part of the EM waves is blocked by the ON-state copper post, resulting in a high isolation ($|S_{21}|$ < -19 dB). On the other hand, insertion loss at the OFF-state is low when most of the EM waves is successfully transmitted ($|S_{21}| \approx$ -0.35 dB).

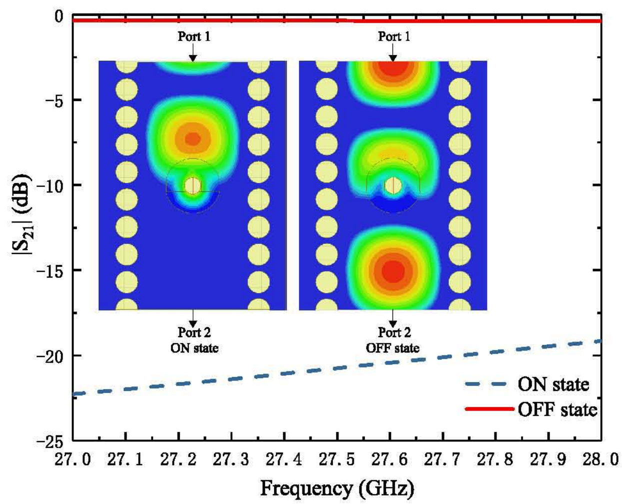

Fig. 3. S-parameters for the SIW switch with different states. (the inset is the electric field distribution inside the SIW switch with different states at 27.5 GHz.)

B. SIW Switch

A SIW switch is designed using HFSS. Fig. 1 illustrates the geometry of the SIW switch, where one copper post is placed in the middle of the SIW. Each copper post is connected to a pair of conductive ring pads on the top and bottom planes, which are surrounded by a pair of ring slots with 0.7 mm width. As shown in the inset of Fig. 1, the ring slots are etched on both copper-cladded surfaces of the SIW, and each ring slot on the top layer of SIW is bridged by two PIN diodes. In this design, DSG9500-000 planar PIN diodes are utilized to provide switching capability. The equivalent circuit of the PIN diode and its physical dimensions are shown in Fig. 2. Accordingly, by changing the states of the corresponding PIN diode, every copper post can operate in ON or OFF state. The ON state means that the copper post is similar to being retained, and the OFF state is similar to being removed from the SIW. As shown in the inset of Fig. 3, the copper post in ON state can successfully block the EM waves, while the copper post in OFF state cannot block the EM waves.

C. Gain Enhancement

As is well known, the conventional SIW H-plane horn features poor radiation performance. To solve this issue, dielectric lens is usually placed in front of the SIW horn aperture to improve antenna gain [12]. However, the gain improvement is limited. In this design, a printed lens is developed to further enhance antenna gain.

Fig. 4 shows the gain comparison between the SIW horn antenna loaded with the dielectric lens and the printed lens. As shown, a maximum gain improvement around 6 dBi is achieved by using the proposed printed lens.

III. Simulation Results and Discussion

To demonstrate the functionality of the proposed SIW horn, only single SIW switch operates in OFF state, while the other five SIW switches work in ON state, as shown in Fig. 5. Fig. 6 shows the reflection coefficients and realized gains of the proposed SIW horn antenna. The pointing of the blue arrow

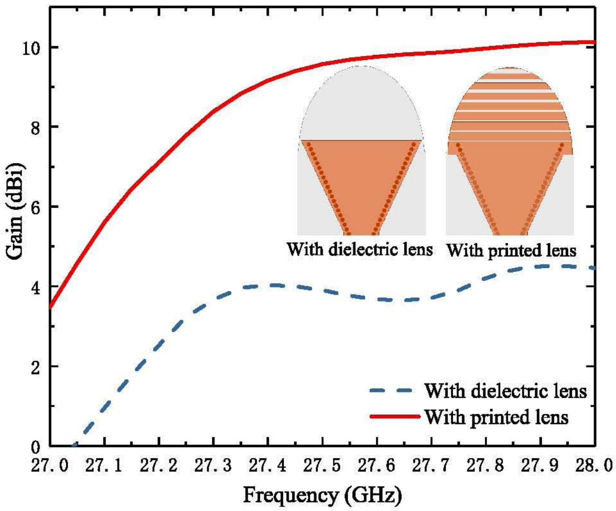

Fig. 4. Simulated gain for the SIW horn antenna loaded with dielectric lens and printed lens.

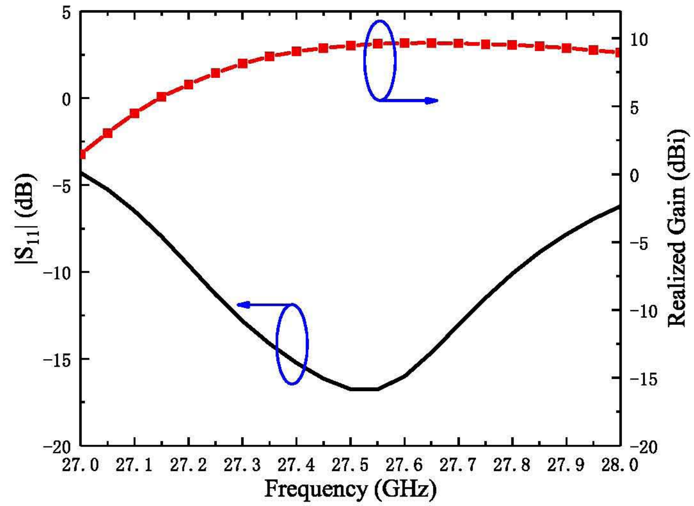

Fig. 6. S-parameters and realized gain for the proposed SIW horn antenna.

represents the ordinate corresponding to each curve. As shown, the simulated impedance bandwidth is about 2.2% for $|S_{11}| <$ -10 dB from 27.2 to 27.8 GHz. Within the operating band, the simulated gain varies between 6.8 and 9.5 dBi. The simulated radiation patterns at frequencies of 27.2, 27.5, and 27.8 GHz are illustrated in Fig. 7. Fig. 7 also indicates that the directional radiation patterns have high front-to-back ratio (FBR $>$ 10 dB) and low cross polarization ($<$ -30 dB). Meanwhile, stable directional radiation patterns over the whole operating band can be observed.

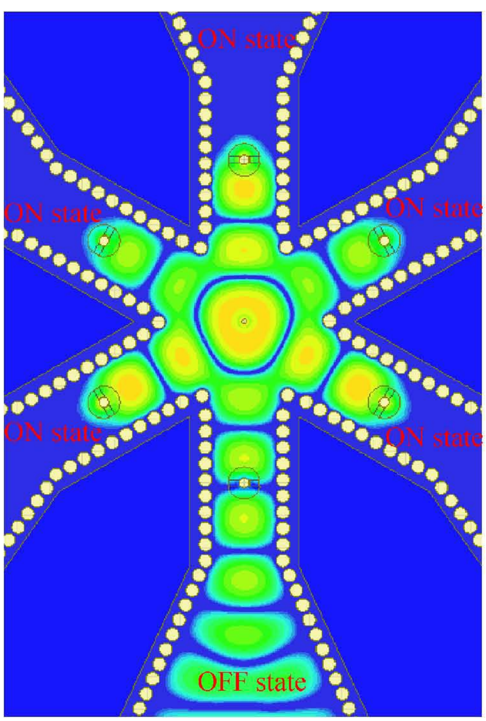

Fig. 5. Electric field distribution inside the proposed antenna with single SIW switch operating in OFF state at 27.5 GHz.

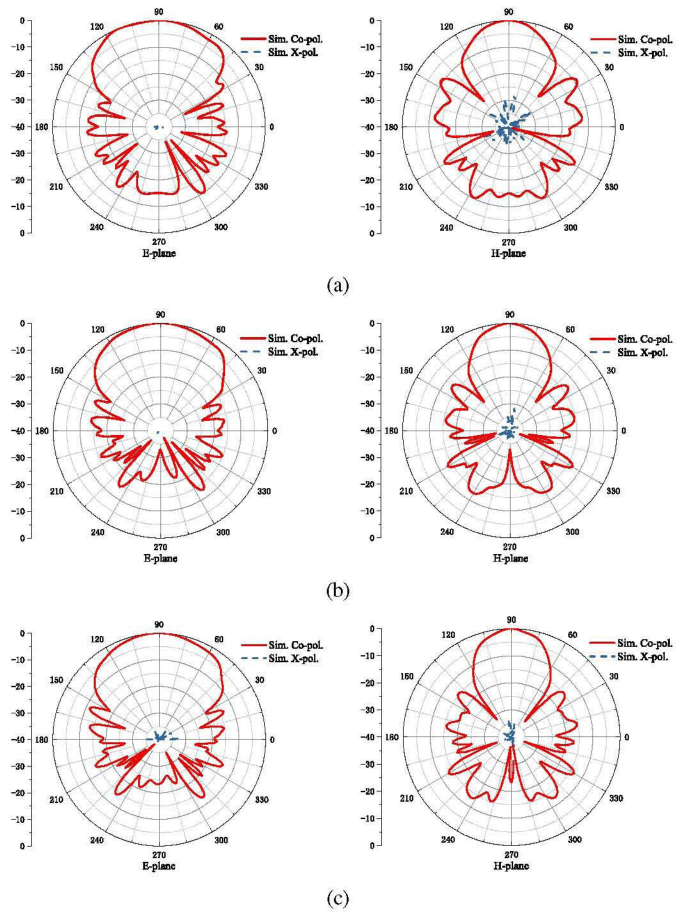

Fig. 7. Simulated radiation patterns of the SIW horn antenna at three different frequencies. (a) 27.2 GHz. (b) 27.5 GHz. (c) 27.8 GHz.

The antenna is also simulated in different beam-steering reconfigurable state by changing the states of different SIW switches. Accordingly, the aperture direction of the proposed antenna can be switched, and the radiation beam can be steered by 60° in the H-plane, as illustrated in Fig. 8. One example of the SIW switch states has been shown in Fig. 5. The corresponding states of other beams forming in different directions are not displayed in this work for simplification. Due to the symmetrical structure around the *xoy*-plane, nearly identical radiation patterns are obtained. The simulated H-plane radiation pattern at 27.5 GHz is rotated 6 times with steps of 60° in the *xoy*-plane. Therefore, a 360° beam-steering reconfigurable capability of the proposed antenna can be observed from Fig. 8.

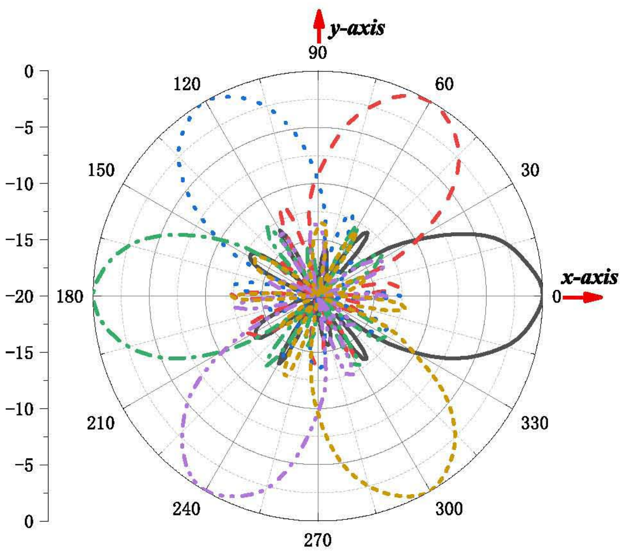

Fig. 8. Beam-steering reconfigurable effect of the proposed antenna at 27.5 GHz.

IV. Conclusion

In this paper, a novel 360° beam-steering reconfigurable SIW horn antenna is proposed. By employing the SIW switches as tuning switches, the radiation direction of the proposed antenna can be electronically controlled. Simulated results illustrate that the radiation beam can be rotated 6 times with steps of 60° in the H-plane. In addition, stable directional radiation patterns with high FBR and low cross polarization are maintained over the entire operating frequency range.

Acknowledgment

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