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Research Article

A Novel SIW H-Plane Horn Antenna Based on Parabolic Reflector

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A new type of H-plane horn antenna based on the parabolic reflector principle is proposed in this paper. The parabolic reflector is constructed with the substrate integrated waveguide technology and is used for generating large radiation aperture and uniform phase distribution at the aperture, yielding a fan beam with very narrow beamwidth in H-plane. A feeding source composed of a probe and an inductive-post reflector is designed as the feed, which can transmit a unidirectional incident wave toward the parabolic reflector. Two metallic strips with post arrays are designed as a transition for the matching between the horn aperture and the free space and also work as a director to realize unidirectional radiation and reduce the front-to-back ratio. The antenna has the advantages of narrow beam, compact size, and easy integration, and the operation bandwidth is from 27 GHz to 35.5 GHz. The experimental results show good agreement with the simulated results.

1. Introduction

The rectangular waveguide horn has been widely used in microwave and antenna applications due to its advantages such as high gain, wide bandwidth, versatility, low standing-wave ratio, ease of excitation, and simplicity in fabrication [1]. However, its application in the planar integration circuits is limited due to its large volume, heavy weight, and cost. This problem is resolved by the new technology of substrate integrated waveguide (SIW) [2, 3], which has low cost and low loss and is easy to be integrated with planar circuits. Therefore, it has developed rapidly since it was proposed and has been widely used in various types of microwave and millimeter-wave components [4–6].

Based on SIW structure an H-plane horn is proposed in [7], which evolves directly from the conventional H-plane horn based on rectangular waveguide. In [8] the dimension of the antenna is successfully reduced by modifying the profile of the SIW horn to be superelliptical. However, the beamwidth is relatively large for all these designs due to the limited effective aperture in H-plane [1], and this is unfavorable for some applications of H-plane horn antenna, such as radar. Thus construction of horn antenna array is required in order to achieve narrower beamwidth in H-plane [9] but is followed by the shortcoming of complex feeding network that occupies more space. Another method is to use metamaterial to generate uniform phase distribution at the horn aperture to achieve high gain and narrow beam [10, 11], but it is difficult to design the complicated structure and the bandwidth is limited due to the characteristic of the metamaterial.

Parabolic reflector antenna is a conventional type of antenna with excellent advantages of high gain and wide bandwidth [12, 13]. It operates based on the principle of geometrical optics, which creates a uniform phase distribution at the large aperture, yielding high gain and wide bandwidth. However, it suffers from large volume, is bulky, and is impossible to be integrated with planar circuits. In [14] an SIW parabolic reflector is used to feed a two-dimensional slot array antenna to realize multibeam radiation, and offset feeding is employed for the parabolic reflector. Compared with the offset feeding, frontal feeding has more difficulties, since the unidirectional illumination on the reflector is difficult to be realized by the frontal feeding in a planar structure. In [15] a method of frontal feeding is used for a parabolic reflecting wall in the design of a surface-wave antenna with wide bandwidth from 6.1 GHz to 18 GHz, which is proposed

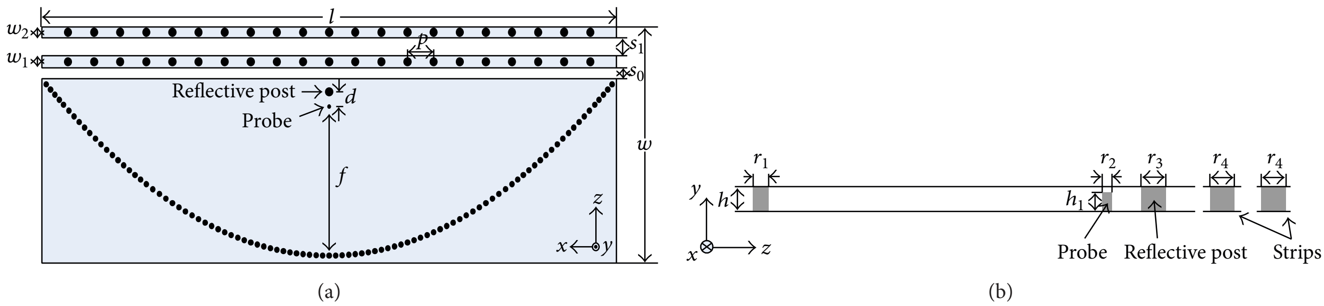


Figure 1: Configuration of the proposed H-plane horn antenna. (a) Top view. (b) Side view (not to scale).

for conformal mounting on aircraft surface. The surface-wave launcher is excited by a coaxial probe, and a metallic capacitive post is used for improving the impedance matching performance. However, as the author claimed, the uniformity of phase distribution at the aperture is not very good due to the superposition of the reflected wave by the parabolic wall and the wave transmitted directly from the probe, because the capacitive post cannot reflect the wave transmitted from the probe. We noticed that the parabolic reflecting principle has great potentials in planar antennas, not only for the two antenna types in [14, 15], but also for the planar horn antennas mentioned above. So in this paper a novel H-plane horn antenna is proposed, in which SIW parabolic reflector is employed to realize narrower fan beam and higher gain in H-plane than the conventional H-plane horn antennas mentioned in [7–9] without constructing antenna array. In addition, an inductive post is adopted and placed near the probe, acting as a reflector to reduce the wave transmitted directly from the probe and hence to improve the uniformity of the phase distribution at the aperture. This design has potential applications in millimeter-wave communication and radar with properties of high direction accuracy and easy integration with planar circuits and devices.

Another important problem for planar horn antenna is the mismatch between the horn aperture and the free space, which also has influence on the radiation property. There are some methods for improving the matching performance, such as loading a dielectric lens [7, 9], printed parallel plates [16], or grating blocks [8] at the horn aperture. In this paper a new transition structure is proposed for improving the matching performance between the horn aperture and the free space.

In summary the antenna proposed in this paper has the following advantages: (1) It works based on the principle of parabolic reflection, so it has a narrow beamwidth in H-plane and a relatively wide bandwidth. (2) It has low profile, can be fabricated with PCB process, and hence is easy to be integrated with millimeter-wave planar circuits. (3) Complex feeding network is not needed, so a lot of space can be saved, making the design simpler. This paper is organized as follows: in Section 2, the configuration of the proposed antenna is described and the operation principle is analyzed; in Section 3, the simulated and experimental results are given and discussed.

2. Configuration and Theory

The overall configuration of the proposed antenna is shown in Figure 1, implemented on a Rogers RT5880 substrate with dielectric constant $\varepsilon_r = 2.2$ and thickness $h = 1.575$ mm. The antenna is composed of three parts: the parabolic reflector, the feeding structure, and the transition. In the part of parabolic reflector, the SIW technology is adopted to construct an array of via holes in parabolic shape. The diameter of via is r_1 and the profile of the parabolic reflecting wall can be expressed as $x^2 = 4fz$, where f is the focal length (f = 30.3 mm). The value of f should not be too small for the purpose of constructing a large radiation aperture. Also, large value of f can reduce the power density along the center line and hence make the illumination on the parabolic reflector more uniform and reduce the return loss. The advantage of the parabolic shape is that the phase wave front emitted from the focal point can be transformed from cylindrical wave to plane wave and reach the uniform phase distribution at the aperture. Therefore, the effective aperture can be significantly enlarged compared with that of the common types of H-plane horn. The feeding structure consists of a coaxial probe and a metallic post, as shown in Figure 1(b). The coaxial probe is the inner conductor of a 2.92 mm airline connector, inserted into the substrate with depth of h_1. The distance between the probe and the parabolic reflecting wall is equal to the focal length f. The metallic post penetrates the entire substrate and acts as a shunt inductive reactance whose value is related with the diameter of the post. This metallic inductive post plays the role of a reflector which reflects the wave transmitted directly from the probe in $+z$ direction, yielding a unidirectional incident wave toward the parabolic reflector. Therefore, the adoption of the inductive post can effectively reduce the influence of the wave transmitted directly from the probe on the phase distribution at the aperture, which is beneficial for constructing the uniform phase distribution and further generating very narrow beamwidth in H-plane.

A transition structure is loaded at the aperture of the parabolic reflector for the purpose of improving the impedance matching between the horn aperture and the free space, as shown in Figure 1. It is composed of two pairs of metallic strips on the top and bottom of the substrate and two arrays of metallic posts along the strips. The two strips have different width, and the metallic posts connect the top and bottom strips. Also, this transition can act as a wave director,

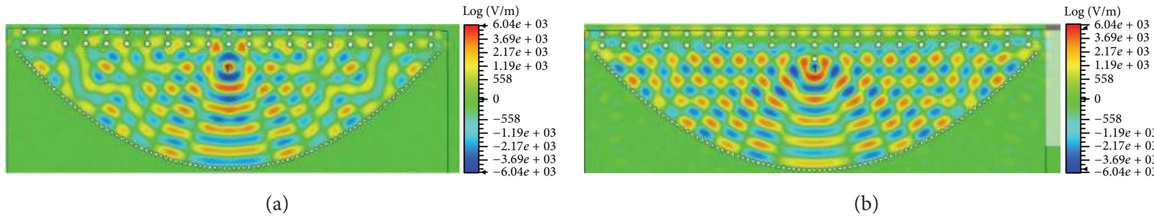


Figure 2: Field distributions inside the substrate: (a) without the reflective post in the feeding structure, (b) with the reflective post in the feeding structure.

leading the wave propagating in $+z$ direction. The performance of the transition can be optimized by adjusting the widths w_1 and w_2 of the strips, the diameter r_4, and the period p of the posts, in order to obtain a better matching performance.

3. Design and Optimization of the Antenna

In this paper the simulation is executed by the commercial software CST Microwave Studio. The optimal design is obtained through many simulations, and the structural parameters are as follows: $f = 30.3$ mm, $d = 3$ mm, $s_0 = 0.2$ mm, $s_1 = 1$ mm, $w_1 = 2.5$ mm, $w_2 = 2$ mm, $p = 6$ mm, $l = 132$ mm, $w = 43.2$ mm, $h = 1.3$ mm, $r_1 = 1$ mm, $r_2 = 0.64$ mm, $r_3 = 1.6$ mm, and $r_4 = 1.6$ mm. The diameters of the coaxial probe and the metallic reflective post are 0.64 mm and 1.6 mm, respectively.

3.1. Field Distribution and Return Loss. The field distributions inside the substrate are shown in Figures 2(a) and 2(b), which are obtained without and with the reflective post in the feeding structure, respectively. By comparing the two figures, we can find that the phase distribution with the reflective post is more uniform at the aperture than that without the reflective post. This is because the reflective post has an inductive reactance and can reduce the wave transmitted by the probe in $+z$ direction, which would interfere with the wave reflected by the parabolic reflector. Therefore, by using the reflective post, a more uniform phase distribution at the aperture can be achieved. So the reflective post in the feeding structure is a key element in the feeding structure. The spacing d between the reflective post and coaxial probe needs to be optimized carefully in order to obtain the optimal result of unidirectional illumination on the parabolic reflector. In addition, the diameter r_3 of the reflective post and the depth h_1 of the probe inserted into the substrate need to be optimized in order to achieve good feeding performance. All of these factors have significant effects on the uniformity of the phase distribution at the aperture. The optimal parameters are obtained by a lot of simulations as follows: $h_1 = 1.3$ mm, $r_3 = 1.6$ mm, and $d = 3$ mm.

Figure 3 shows the reflection coefficient S_{11} of the antenna with and without the inductive reflective post in the feeding structure. It can be seen that the bandwidth of 27 GHz–35.5 GHz can be obtained by both cases, demonstrating that the adoption of the reflective post does not have obvious effect on the bandwidth of the design.

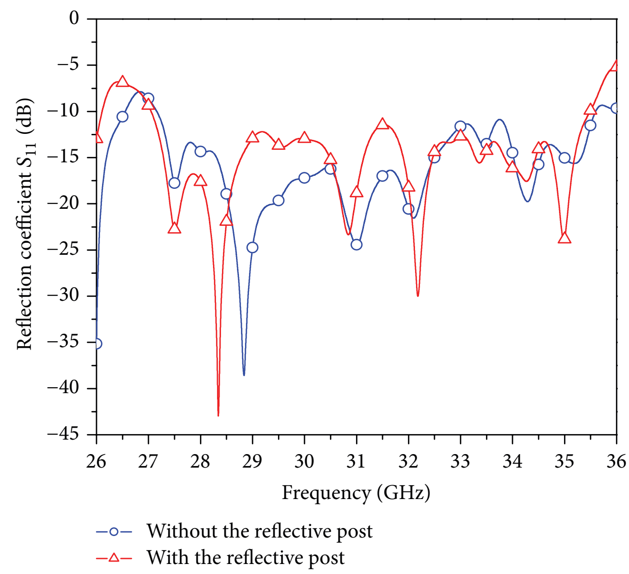


Figure 3: Comparison of reflection coefficient S_{11} of the antenna with and without the reflective post in the feeding structure.

The transition at the aperture of the parabolic reflector in Figure 1(a) is adopted for improving the matching performance between the aperture and the free space. We noticed that in [16] the transition is composed of two identical parallel plates without posts. In this paper the two strips have different widths for more flexible adjustment, and more importantly two rows of metallic post arrays are employed along the strips for better performance. Figure 4 shows the comparison of reflection coefficient S_{11} of the antenna with and without the post arrays in the strips. It can be seen that the reflection coefficient of the antenna can be significantly reduced by mounting the metallic post arrays along the strips, and the −10 dB bandwidth from 27 GHz to 35.5 GHz can be achieved.

The fabricated prototype of the proposed H-plane horn antenna is shown in Figure 5. In Figure 6 the experimental result of the reflection coefficient S_{11} of the antenna is given, showing good agreement with the simulated result.

3.2. Radiation Properties of the Proposed Antenna. The measured and simulated radiation patterns of the proposed horn antenna with the reflective post in the feeding structure and the simulated radiation patterns without the reflective post in E-plane and H-plane at different frequencies are depicted in

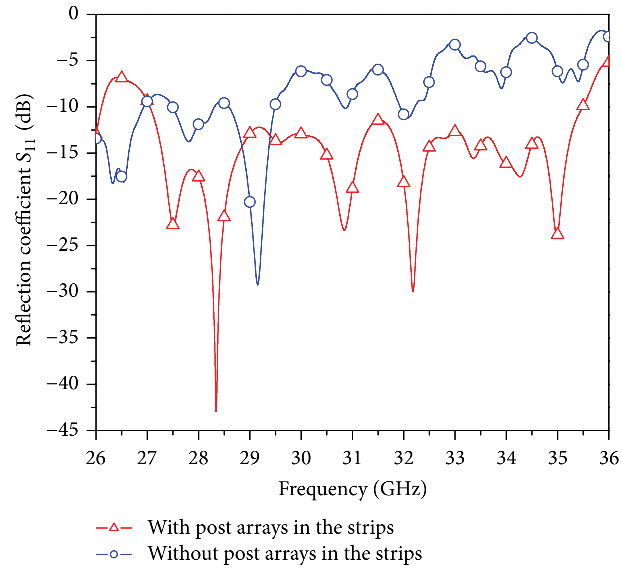
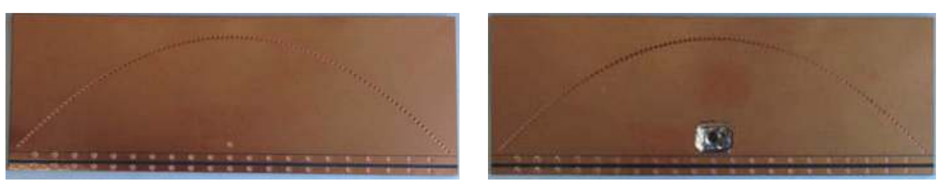


Figure 4: Comparison of S_{11} of the antenna with and without two rows of metallic post array in the transition.



(a) (b)

Figure 5: Prototype of the H-plane horn antenna. (a) Top view. (b) Bottom view.

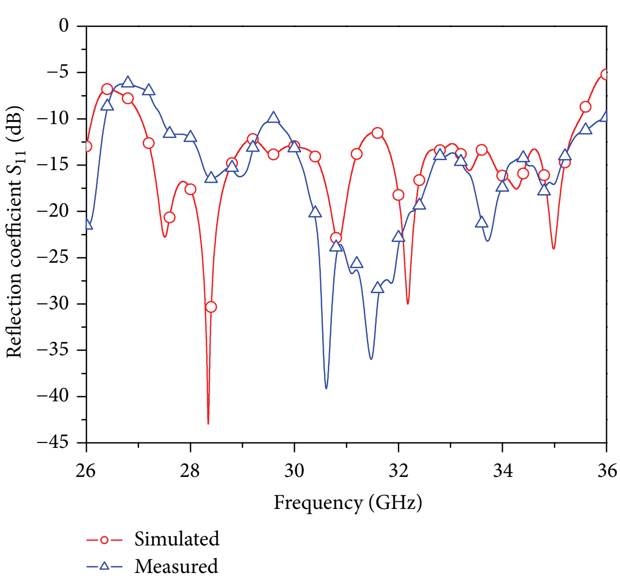


Figure 6: Measured and simulated S_{11} of the H-plane horn antenna.

Figure 7. It can be seen that the antenna has a fan beam, and the radiation patterns in both E- and H-planes are very stable when the frequency changes in the bandwidth. The main beam always points to the $+z$ axis. The measured radiation pattern and the simulated radiation pattern are well matched. Also, it can be observed that the proposed horn antenna with reflective post has higher gain than that without the reflective post. This is because the reflective post can reduce the wave transmitted by the probe in $+z$ direction and hence generate a more uniform phase distribution at the aperture, as discussed in Section 3.1.

The results of the simulated and measured peak gain of the proposed horn antenna are presented in Figure 8. It can be seen that the simulated peak gain increases from 12.7 dBi to 18 dBi when the frequency changes from 27 GHz to 36 GHz. The measured results of peak gain match well with the simulated results. In addition, the simulated peak gain when the reflective post is not employed in the feeding structure is given for comparison. It can be seen that the peak gain with the reflective post is higher than that without the reflective post in the whole working frequency range.

The simulated and measured results of 3 dB beamwidth in H-plane of the proposed antenna are shown in Figure 9. As depicted in Figure 9, the 3 dB beamwidth in H-plane has a small value, decreasing from 4.5° to 2.9° when the frequency changes from 27 GHz to 36 GHz. The measured results match well with the simulated results at the testing frequencies of 30 GHz, 32 GHz, and 34 GHz.

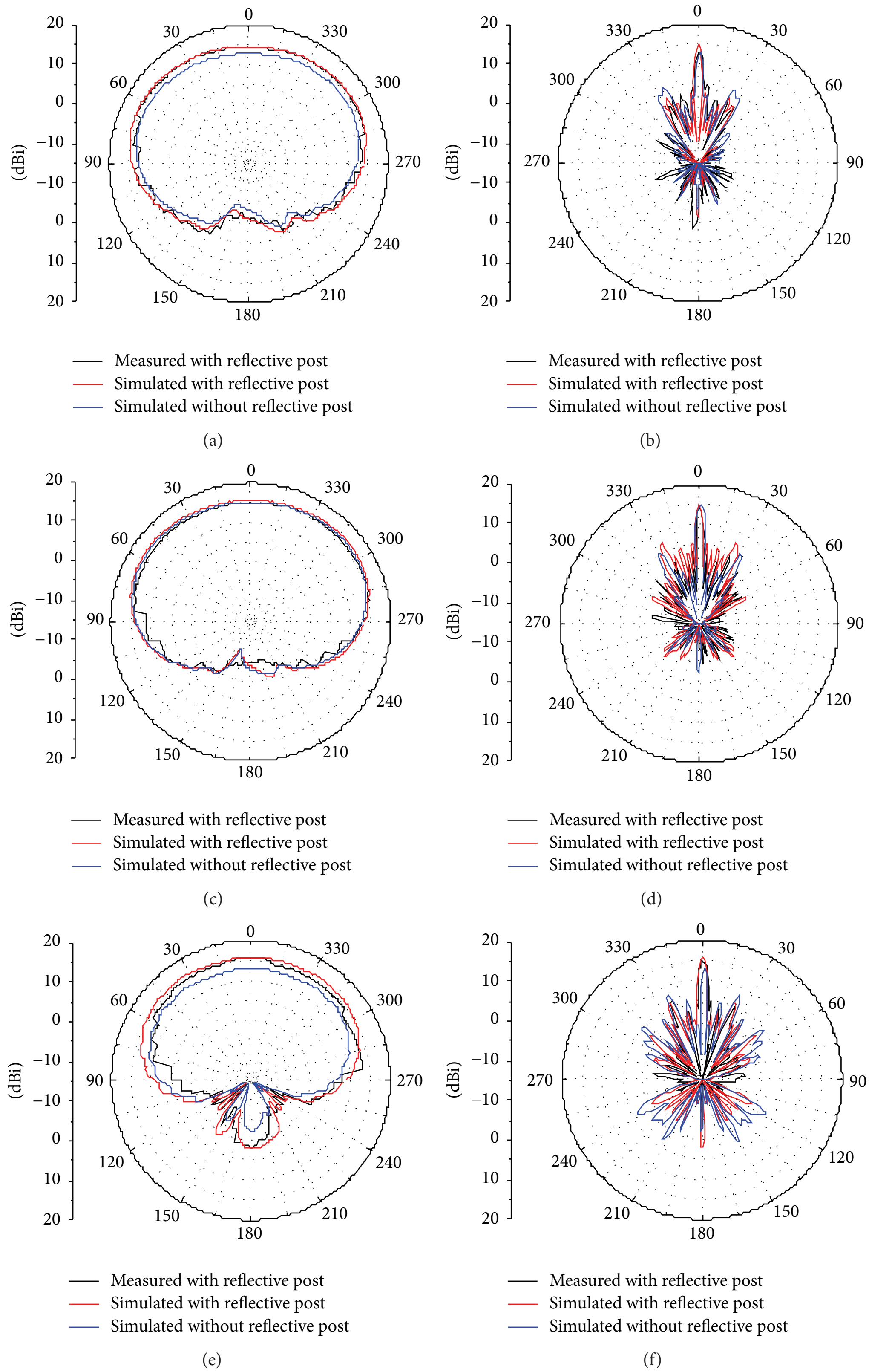


Figure 7: Measured and simulated radiation patterns of the H-plane horn antenna with the reflective post and the simulated radiation patterns without the reflective post. (a) E-plane at 30 GHz. (b) H-plane at 30 GHz. (c) E-plane at 32 GHz. (d) H-plane at 32 GHz. (e) E-plane at 34 GHz. (f) H-plane at 34 GHz.

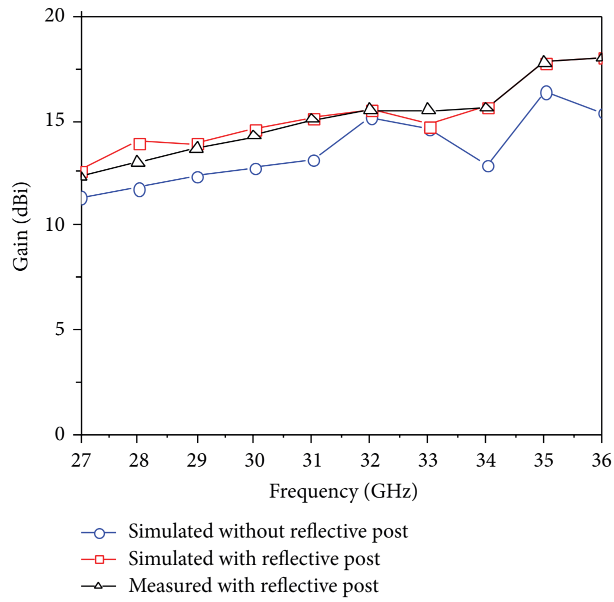


Figure 8: Measured and simulated peak gain of the H-plane horn antenna with the reflective post and the simulated peak gain without the reflective post versus frequency.

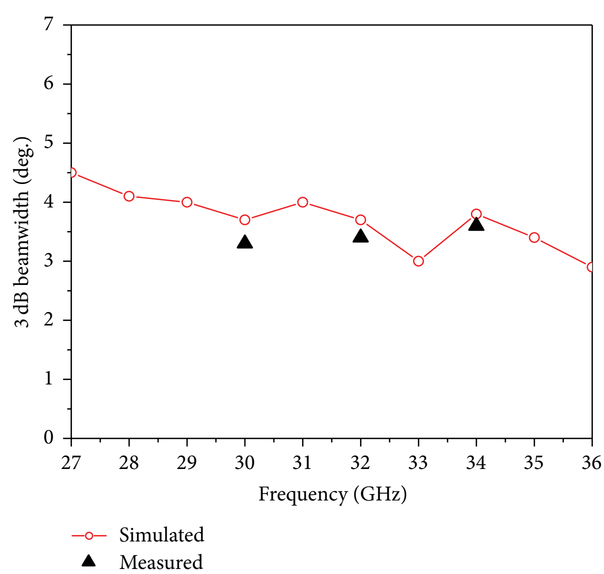


Figure 9: Measured and simulated 3 dB beamwidth of the H-plane horn antenna versus frequency.

4. Conclusion

A novel SIW H-plane horn antenna is proposed in this paper, in which a parabolic reflector structure is adopted to construct a uniform phase distribution at the aperture of the antenna in order to realize a narrow beamwidth in H-plane. A new transition structure with metallic post arrays is used at the aperture for matching with the free space. The proposed antenna can achieve a bandwidth from 27 GHz to 35.5 GHz. The radiation pattern and the main beam are very stable in this bandwidth, and a very narrow beam in H-plane can be achieved. This design has the advantages of compact size, easy feeding, narrow beamwidth in H-plane, and stable radiation properties and is suitable for the integration with millimeter-wave planar circuits.

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

Acknowledgments

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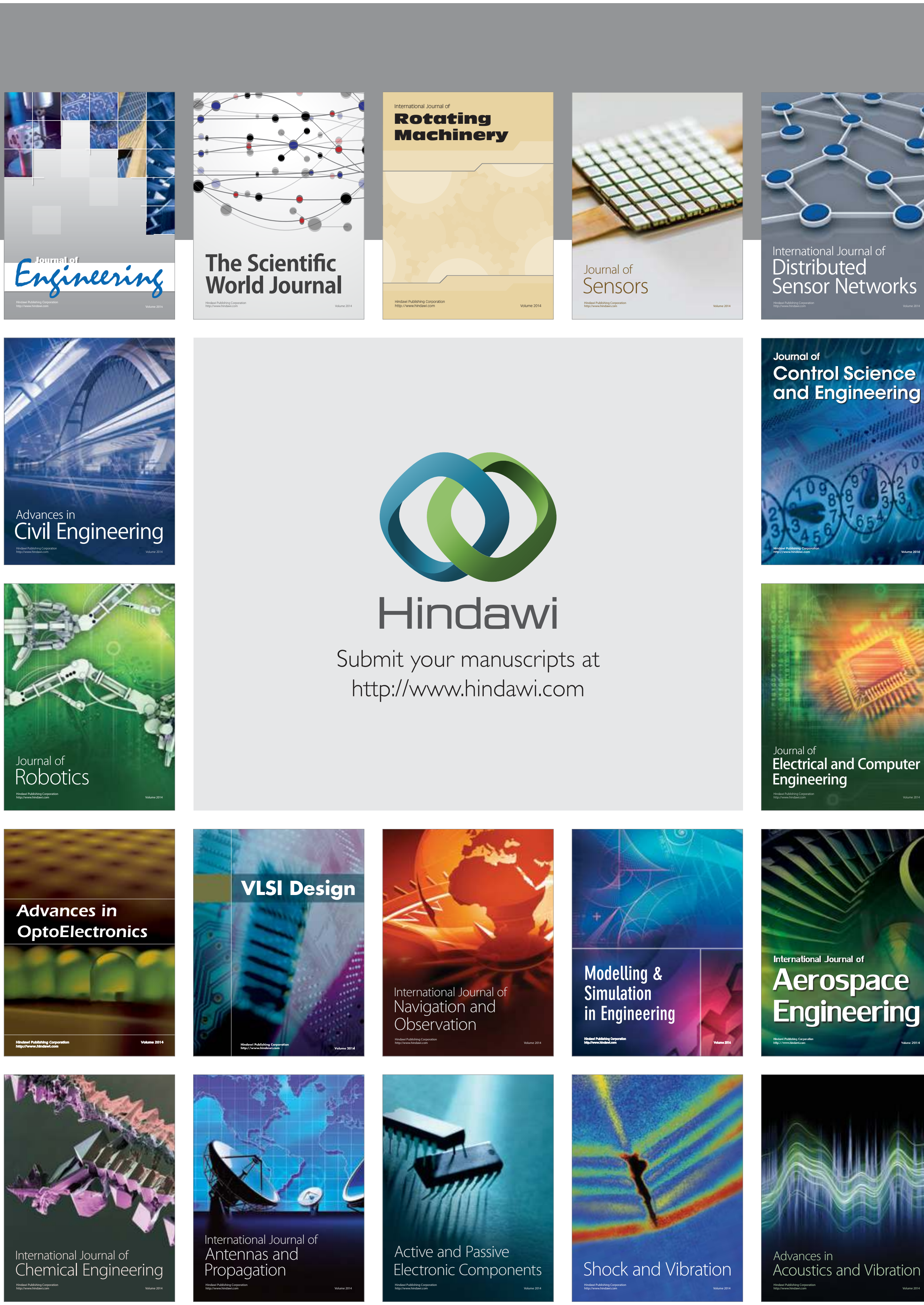
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