

# A SIW Horn Antenna without Broad Wall Loaded with Trapezoidal Air Slot

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**Abstract** — In this paper, a SIW horn antenna without broad wall loaded with trapezoidal air slot is proposed, processed, and tested. Based on the SIW horn antenna, this antenna strips off the wide wall at the horn diameter, introduces surface waves on the surface of the dielectric substrate, and improves the impedance matching between the antenna and free space. Further, trapezoidal air slots are loaded on the exposed dielectric substrate, gradually changes the dielectric constant of the dielectric substrate, so that the dielectric constant of the dielectric substrate can get closer to which of air, and the working bandwidth can be further expanded. The actual measurement results show that the working bandwidth of the antenna is 15.2-38GHz, the relative bandwidth reaches to 85.7%, and the maximum gain in the band is 9.1dBi.

**Index Terms** — Broadband antenna, horn antenna, impedance matching, substrate integrated waveguide.

## I. INTRODUCTION

The horn antenna is a widely used in microwave antenna. The traditional horn antenna is gradually expanded from the terminal of the metal waveguide. It has the advantages of simple structure, wide frequency bandwidth, large power capacity, and convenient adjustment and use [1]. But there are also significant disadvantages such as: high profile, large volume, and high processing cost. With the introduction of substrate integrated waveguide technology (SIW), horn antennas based on SIW technology entered our field of vision [2]. This horn antenna has a lower profile and cheaper processing cost, which solves the shortcomings of the traditional metal waveguide horn antenna. However, due to the different dielectric constants of the dielectric substrate and the free space, electromagnetic waves emitted from the dielectric substrate to the free space may have an impedance mismatch, which leads to a narrow working bandwidth of the antenna.

In order to solve this problem, a horn antenna loaded with a dielectric plate was proposed [3-4]. A semi-circular or rectangular dielectric substrate was extended in the front section of the horn antenna as an impedance transformer of the antenna, which expanded the horn the bandwidth of the antenna. Further, on the dielectric substrate of the antenna extension, air holes of different sizes are punched to further increase the bandwidth of the horn antenna [5]. In addition, the method of introducing additional resonance frequency by loading metal blocks on the extended dielectric substrate has also been proposed [6-7]. This method requires a thinner horn antenna and a lower antenna profile.

A corrugated horn antenna has been proposed [8]. The corrugated structure is adopted at the horn diameter. The antenna has a good bandwidth expansion in low frequency bands. The antenna is integrated on a single-layer dielectric substrate, which is easy for planar circuit integration. Several non-planar horn antennas have also been reported [9-10]. Loading the traditional SIW horn antenna with an inhomogeneous-polarizer or using a pyramid-type horn antenna based on coupled feed can enhance the radiation performance of the antenna but cannot meet the requirements of single layer, low profile antenna.

In order to further miniaturize the horn antenna, a horn antenna without a wide wall has entered our field of vision [11-12]. Based on the traditional SIW horn antenna, the metal broad wall at the horn diameter is stripped off, and a plane wave is introduced on the antenna surface to improve the impedance matching between the antenna and free space. Further, air holes are punched on the exposed dielectric substrate to expand the bandwidth of the antenna.

Other forms of wideband antennas also offer inspiration. A simple method is proposed for enhancement in bandwidth and gain of the self complementary Bowtie antenna. Using this simple method, by making variation

of the single dimension of the structure of the antenna, the bandwidth is improved by 21% and return loss S11 is also improved of whole of the band of interest [15]. A novel printed monopole antenna with defective ground structure is proposed. The initial design is further modified to enhance the impedance bandwidth and gain by employing a defective ground structure in the coplanar ground plane of the monopole patch [16]. Several high-performance Sierpinski fractal antennas have been reported, among which the feeding position has become a key factor [17,19].

In this article, we propose a SIW horn antenna without broad wall loaded with trapezoidal air slot. On the basis of the traditional horn antenna, the metal wide wall at the horn diameter is stripped off. And on the bare dielectric substrate, trapezoidal air slots are punched. Without enlarging the size of the antenna, the broadband operation of the antenna is realized. This antenna has a simple structure and low processing cost, and will have a good application prospect in the actual working environment.

## II. ANTENNA STRUCTURE AND OPTIMIZATION

### A. Antenna structure

The antenna is a single-layer dielectric substrate, the material of which is FR-4. Its dielectric constant is 4.3, and the loss tangent is 0.025.

The structure of the antenna is shown in Fig. 1, which is successively divided into microstrip line part, SIW part and horn caliber part. The impedance of the microstrip line is 50 ohms, which can be well matched with the SMA connector. The surface metal, medium substrate, bottom metal plate and metal vias form the SIW structure. To avoid energy leakage, the diameter  $d$  of all metal vias is 0.4mm, and the spacing  $x$  between the metal vias is 0.7mm.

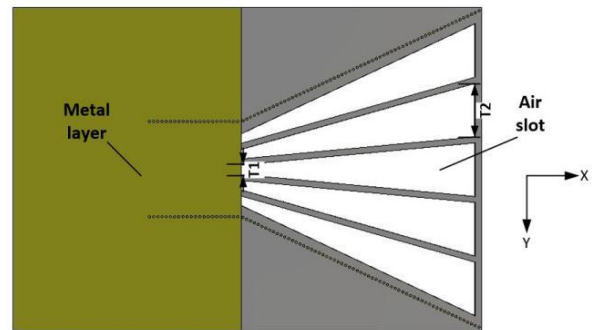
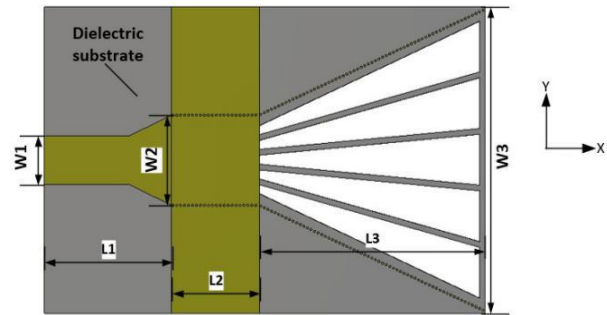
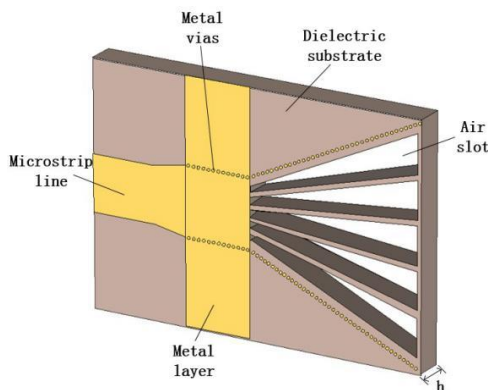


Fig. 1. Antenna structure.

Electromagnetic waves are fed into the SIW cavity by means of microstrip feeding. The main mode of transmission is transformed from the TEM mode on the coaxial cable to the TE mode in the SIW cavity. Starting at the junction of the rectangular SIW cavity and the horn diameter, the metal wide wall was stripped, and the surface wave was added to the TE mode, which greatly improved the impedance matching between the antenna and the free space.

### B. Antenna design principles and optimization

The data in Fig. 1 is shown in Table 1.  $W1$  is the width of the microstrip line, and its value is to comply with the impedance matching of 50 ohms. Because we know that the main mode transmitted in the SIW cavity is  $TE_{10}$  mode, according to formula (1) we can calculate the width  $W2$  of the SIW cavity:

$$W2 = \frac{c_0}{f_{c(TE_{10})} \sqrt{\epsilon_r}} + \frac{d^2}{1.1x} + \frac{d^3}{6.6x^2}, \quad (1)$$

where  $d$  and  $x$  are the diameter of the metallized via and the distance between the vias,  $f_c$  is the cutoff frequency corresponding to the  $TE_{10}$  mode, and  $c_0$  is the speed of light in free space.

Table 1: The specific value of the parameter (unit:mm)

W1	W2	W3	L1	L2	L3
8.6	15.9	54	22.5	15.5	40
h	T1	T2	d	x	
4.3	1.6	8.97	0.4	0.7	

Further, in the simulation software CST2015, we establish an antenna model and set the width of the SIW cavity to the calculated value w2. It can be seen that the antenna has a very wide bandwidth, as shown in Fig. 2, which proves that our calculation is reasonable. For 38GHz and above, the gain of antenna is too low at this time, we do not regard this as our working bandwidth. The definition of dBi is the antenna gain db value obtained by using the ideal point source omnidirectional antenna as reference.

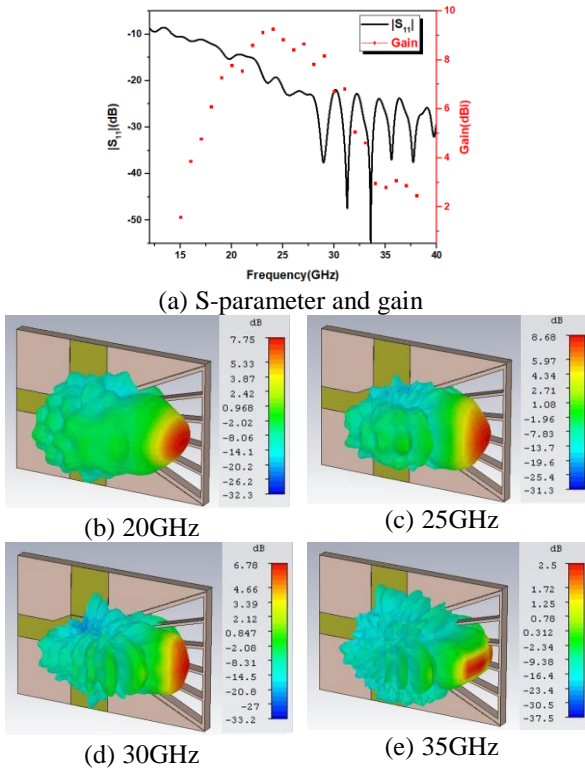


Fig. 2. Simulated S-parameter curve and gain.

The lengths of the upper and lower sides of the trapezoidal air gap are T1 and T2. The setting of these two values must first consider the level of processing technology. In order to ensure the stability of the structure of antenna, the minimum distance between two adjacent slots should be greater than 1mm. The following is the formula (2) for changing the dielectric constant of the dielectric substrate by drilling and other methods. In the case of our trapezoidal slot, the specific formula (3) is proposed. It can be seen that our scheme

has nothing to do with frequency, and is also available for broadband transmission:

$$\epsilon_{\text{reff}} = \frac{\epsilon_r S_a - S_w + S_w}{S_a}, \quad (2)$$

$$\epsilon_{\text{reff}} = \frac{\epsilon_r [W_2 + W_3 - N T_1 + T_2] + N T_1 + T_2}{W_2 + W_3}, \quad (3)$$

where  $S_a$  is the area of the dielectric plate at the entire horn diameter,  $S_w$  is the total area which is dug by punching or other methods, and  $N$  is the number of trapezoidal slots.

When the FR-4 substrate works at 20GHz or above, the medium loss is too large and it is difficult to obtain a high gain. In our design, due to the introduction of trapezoidal air slot, the medium loss of FR-4 was reduced to a certain extent. The antenna can still get high gain at 20-25GHz. To verify this view, we compare the gain of the antenna under without slot and different size slots. The results are shown in Fig. 3. It can be seen that the larger the slot area is higher the gain at high frequencies. However, the slot size has an upper limit. Oversize slot will lead to the instability of the structure of antenna and the rapid change of dielectric constant.

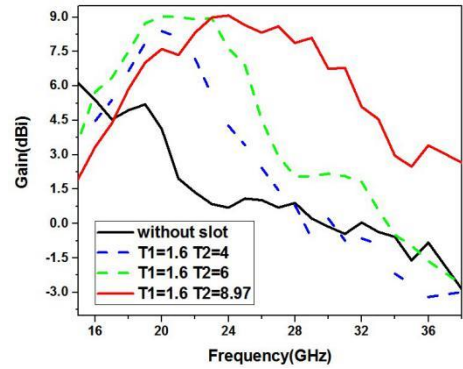


Fig. 3. Antenna gain of different sizes of slot.

Synthesizing the factors above, the values of T1 and T2 are finally set, at this time the dielectric constant of the dielectric substrate is slowly changed from 2.64 to 1.56, reducing the mismatch caused by the sudden change of the dielectric constant.

### III. SIMULATED AND MEASURED RESULTS

On the basis of the above scheme, we have established a model in the electromagnetic simulation software CST2015 and optimized the parameters. In order to further verify the performance of the antenna, we prototyped the proposed antenna. The S-parameters of the antenna were tested using a vector network analyzer and compared with our simulated results. The specific data is shown in Fig. 4.

It can be seen that the simulated and measured results of the antenna match well, which is due to the simple structure of the antenna, and the influence of processing accuracy is considered in the design. The antenna we proposed achieves broadband transmission from 15.2GHz to 38GHz without increasing the size of the antenna, which is very rare.

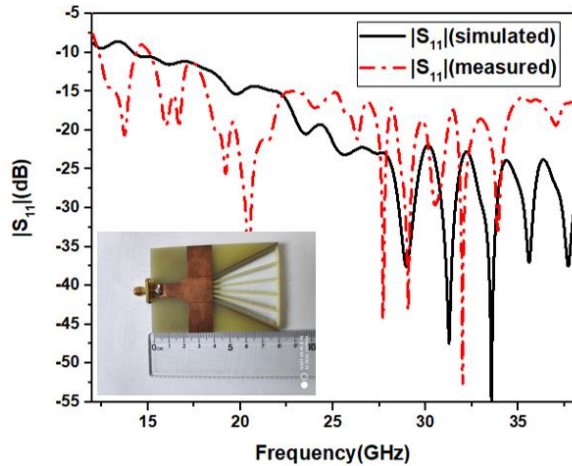


Fig. 4. Antenna simulated and measured S-parameter comparison.

In the microwave dark room, the radiation pattern and antenna gain of the antenna were tested. The simulated and measured gain of the antenna are shown in Fig. 5. It can be seen that the two are basically consistent. In particular, the high-gain region of the antenna belongs to 18GHz to 32GHz. When the antenna works in the low-frequency region, the lower the frequency is, the longer the wavelength is. For such wavelengths, the size of the antenna is relatively small, so the overall gain is small. When the antenna works in the high-frequency region, combined with the above-mentioned formula (1), the main mode of the antenna transmission is no longer the standard TE<sub>10</sub> mode, which affects the radiation of antenna to a certain extent, resulting in a decrease in gain.

The comparison of the radiation pattern of the simulated and measured of the antenna is shown in Fig. 6. We selected four frequency points for comparison. The simulated and measured results are not only agree, but also have good radiation characteristics for the horn antenna. In order to better reflect the advantages of our proposed antenna, we compared with the previous work. The results are shown in Table 2. The compared items include size, maximum gain in band, and operating

frequency. It can be seen that our antenna achieves broadband transmission without increasing the size of the antenna, and with high gain at the same time.

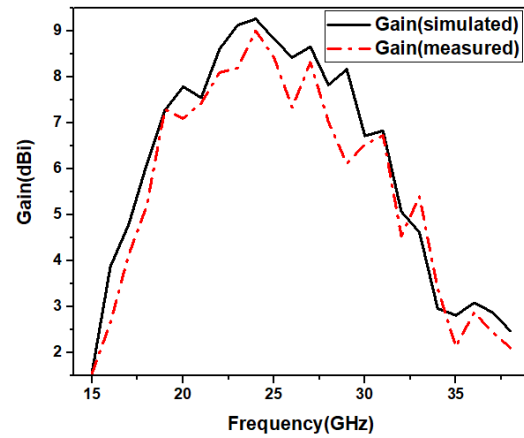
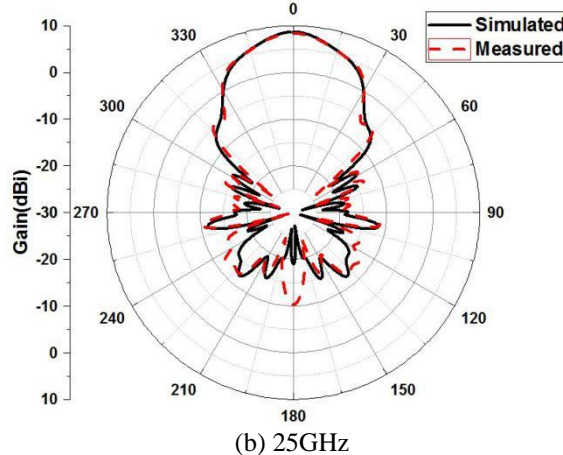
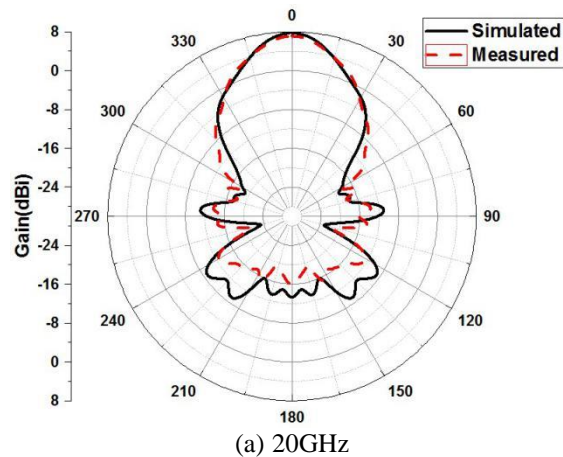


Fig. 5. Comparison of simulated and measured gain.



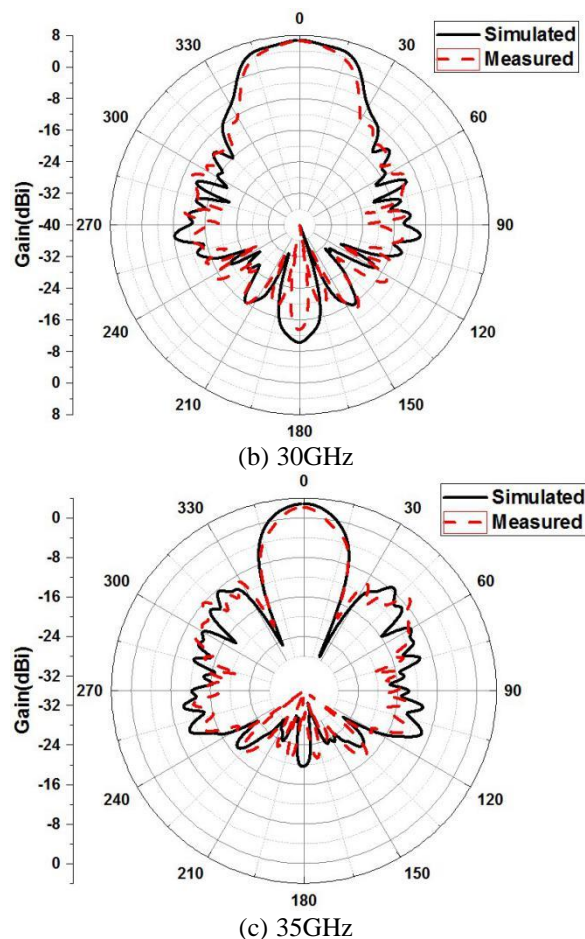


Fig. 6. Simulated and measured direction diagram of each frequency point.

Table 2: Antenna performance comparison

Ref.	Frequency (GHz)	Band-width	Maximum Gain (dBi)	Single Layer
[11]	17.7-26.7	40.5%	9.2	yes
[12]	19.1-27.4	35.7%	8.9	yes
[13]	26.7-29.1	8.6%	6.54	yes
[14]	31-58	60.7%	19	no
Proposed	15.2-38	85.7%	9.1	yes

#### IV. CONCLUSION

In this paper, a SIW horn antenna without broad wall loaded with trapezoidal air slot is proposed, processed, and tested. Based on the SIW horn antenna, the impedance bandwidth of the antenna is improved by stripping the wide metal wall at the horn aperture and etching the air slot on the exposed dielectric plate. Furthermore, the air slot reduces the medium loss of the antenna and improves the gain of the antenna when it works at high frequencies. The physical size of the antenna is 78mm\*54mm\*4.3mm, the measured impedance bandwidth is 15.2-38GHz, and the maximum gain in the band is 9.1dBi. This horn

antenna is simple in structure and low in cost, which has a good application prospect in practical engineering.

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