A Broadband Low Profile SIW H-plane Horn Antenna With Improved Performance

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***Abstract*—This paper is presenting a broadband, low-profile ($0.008\lambda_0$) substrate-integrated waveguide (SIW) H-plane horn antenna with the reduced side lobes and improved front-to-back ratio (FTBR). This is achieved implementing three rectangular slots near the coaxial feed. The hexagonal slots in front of the horn aperture are used to improve impedance matching. The measured fractional impedance bandwidth of 29.5% (3.25 GHz), the maximum gain of 5.52 dBi (minimum: 2.85 dBi), the maximum radiation efficiency of 95.99%, the FTBR of 15.83 dB, and the low cross-polarization level have been achieved at the frequency of 9.85 GHz.**

***Index Terms*—Horn antenna, thin substrate, substrate integrated waveguide (SIW), broadband, improved FTBR and impedance matching.**

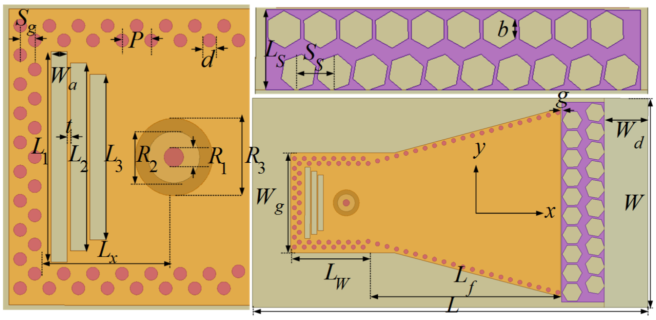

Fig. 1. Geometry and dimensions of proposed antenna.

I. Introduction

Nowadays, the horn aperture antennas are popular for their structural simplicity, high gain, and ease of excitation. However, the non-planar geometry limits their usage due to their incompatibility with printed circuit board realization of other antennas. Their implementation using substrate-integrated waveguide (SIW) technology offers the possibility of integration of these antennas with other planar printed radio frequency (RF) components. However, using the thin substrates for printed circuits creates the difficulties in realization of the planar version of horn antennas with high performance. The most degraded parameters are usually impedance matching and the antenna bandwidth. Significant efforts have been made toward improving the SIW H-plane horn antenna parameters. In [1], the reduction of side-lobe level to -15 dB and improvement in the front-to-back ratio (FTBR) is achieved by integrating rectangular metal patches and dielectric loading to the aperture of the SIW H-plane horn antenna. However, due to the feeding method employed, the fraction bandwidth is limited to only 2%. This is attributed to incorrect impedance match, and can be improved by employing the matching techniques proposed in [2]–[5]. In [6], the authors have achieved a low profile ($0.068\lambda_0$) horn antenna with the fractional bandwidth of 14.7% and the FTBR of 16 dB.

This work aims to improve the impedance matching, reduce the side lobes, improve the FTBR. Furthermore, this paper presents a thin substrate ($0.008\lambda_0$) realization. Initially, the horn is designed for X-band using the SIW concept, and then the additional steps towards improving the antenna parameters are taken. Two rows of hexagonal slots are used between the horn aperture and free space to obtain a good impedance matching and broader bandwidth. On the coaxial feed side, three rectangular slots are implemented. This provides an improved radiation pattern with the reduced side lobes and the enhanced antenna FTBR. A dielectric slab located between hexagonal slots and air medium additionally increases the horn's gain.

II. Antenna Design and Analysis

Fig. 1 shows the enlarged hexagonal slots section (top right side), the view of the whole antenna waveguide section, and the enlarged view of the coaxial feed (left side) with rectangular slots. Hence, the antenna structure consists of four sections: waveguide with feed and rectangular slots, flare horn, impedance matching (hexagonal slots), and dielectric slab (enhancing the gain). At first, a simple SIW-based *H*-plane horn antenna with a coaxial feed is designed and simulated (see Fig. 2). The thickness of the substrate is 0.25 mm ($0.008\lambda_0$). It is known that the SIW impedance is

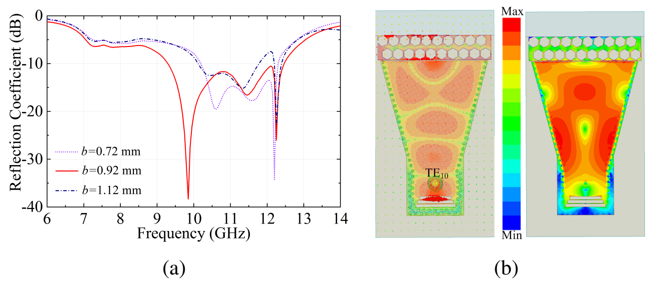

Fig. 2. Effect of b on reflection coefficient (a) and electric field (left) and surface current (right) distributions at 10 GHz (b).

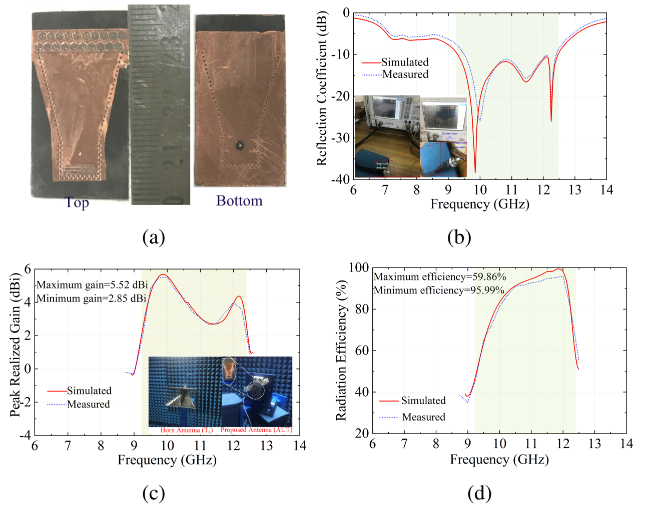

Fig. 3. The proposed antenna and simulated and measured results: (a) Fabricated prototype, (b) Reflection coefficient, (c) Peak realized gain, and (d) Radiation efficiency measurement.

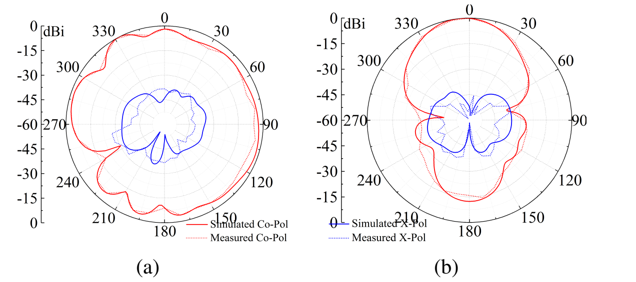

Fig. 4. Normalized radiation patterns: (a) E-plane, (b) H-plane at 9.85 GHz

Table I
COMPARISON OF COMPETITIVE AND PROPOSED ANTENNA

Ref.	h (mm/λ_0)	FBW (%)	Gain (dBi)	η (%)	FTBR(dB)
[3]	1.524/0.086	16	7.1	NR	15
[5]	1.524/0.08	1.3	5.7	NR	2
This work	**0.25/0.008**	**29.5**	**5.52**	**95.99**	**15.83**

decreasing as the substrate thickness of a SIW horn antenna is reduced. To overcome this decreasing, two rows of hexagonal slots are etched between the horn aperture and free space. As a result, the impedance matching becomes better. The gap g between the aperture and the matching section also helps to get a better match due to the electrical coupling. The side b of the hexagonal slot is fixed using the parametric analysis. As shows Fig. 2(a), when b is varied from 0.72 mm to 1.12 mm with the step of 0.2 mm, the value of b=0.92 mm is providing the best impedance matching in the whole band. Three rectangular slots are etched near the feed (see left part of Fig. 1) to suppress the side lobes and improve the antenna FTBR of the horn. At the same time, these slots are degrading the gain. The dielectric slab put after hexagonal slots is helping to compensate this decrease and provides the gain improvement. The electric field and surface current distribution are shown in Fig. 2(b). It is confirmed that the antenna propagates the TE_{10} mode (dominant mode). The final designed parameters were fixed using parametric analysis. The dimensions of horn antenna are as follows: $P = 0.8$, $d = 0.4$, $S_g = 0.45$ $L_x = 4.1$, $R_1 = 0.7$, $R_2 = 0.9$, $R_3 = 1.8$, $W = 19.14$, $L = 36.24$, $S_s = 1.75$, $L_s = 3.9$, $b = 0.92$, $g_0.1 = 3$, $L_f = 18.24$, $L_w = 7.1$, $W_g = 9.14$, $W_d = 4$, $W_a = 0.1$, $L_1 = 6.5$, $L_2 = 5.8$, $L_3 = 4.98$, $h = 0.25 = 0.009\lambda$; unit: millimeters. The substrate thickness is 0.25 mm, i.e., less than $0.008\lambda_0$ at 9.85 GHz. The structure was implemented with the Rogers RT Duroid 5880 (TM) material ($\varepsilon_r = 2.2$ and dissipation factor ($\tan\delta$)=0.0009). The simulations were carried out using Ansys HFSS ver. 2020R2.

III. EXPERIMENTAL VALIDATION

The top and bottom views of the antenna prototype are illustrated in Fig. 3(a). The simulated and experimental results of the reflection coefficient and the measurement setup with VNA are shown in Fig. 3(b). The measured fractional bandwidth (FBW) of 29.5% (simulated: 33%) is achieved. Fig. 3(c) shows the experimental values for maximum and minimum peak gains of 5.52 and 2.85 dBi (simulated:5.56 and 2.95 dBi). Fig. 3(d) shows the maximum and minimum measured radiation efficiencies as 96 and 59.86% (simulated: 99 and 62.56%) at the whole band (9.25-12.5 GHz). The measured and simulated normalized radiation patterns are plotted in Fig. 4. The measured FTBR of the H-plane is about 15.83 dB (simulated: 13.37 dB) at 9.85 GHz. Then, the measured cross-polarization level below -45 dB (simulated: -50 dB) is achieved. One can see that the simulated and measured antenna characteristics and parameters are in a good agreement. Table I gives a comparison of the presented and the state-of-the-art reported antennas.

IV. CONCLUSION

In this work, a broadband, low-profile SIW-based planar antenna with improved radiation characteristics and enhanced FTBR has been discussed. This H-plane horn antenna has been designed, fabricated, simulated, and experimentally tested. The antenna achieved a measured FBW of 29.5%, peak gain of 5.52 dBi, the radiation efficiency of 95.99%, FTBR of 15.83 dB, and cross-polarization level below -45 dB at 9.85 GHz (simulated: 10 GHz). This antenna can be suitable for X-band applications.

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