A Low Profile Improved Gain SIW-Based H-Plane Horn Antenna for X-Band Application

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***Abstract*—In this paper, a substrate integrated waveguide (SIW)-based H-plane horn antenna with enhanced gain made on a very thin substrate (0.009λ_0) is proposed for X-band application. Improved impedance matching is obtained by implementing three stepped quarter-wave transformers in the feed section and four circular slots at the front of the horn. Two rows of teflon vias are used to enhance the gain, and the corrugated wall technique is also implemented to improve other antenna radiation characteristics. The measured fractional impedance bandwidth of 5.22%, the gain of 10.82 dBi, the radiation efficiency of 88.56%, the front-to-back ratio of ≈15 dB, and the low cross-polarization level have been achieved at 10.71 GHz.**

***Index Terms*—Horn antenna, low profile, Substrate Integrated Waveguide (SIW), quarter-wave transformer, impedance matching, high gain.**

I. Introduction

The rectangular horn antenna is one of the most popular used antennas in microwave applications. Yet, because of their low front-to-back ratio (FTBR) and impedance mismatch, substrate-integrated-waveguide (SIW) horn antennas are less frequently utilized than metallic rectangular horn antennas. The terminology of low profile or thin substrate is used to mean a thickness of substrate of about 0.1λ_0. Now, the impedance of the SIW continues to decrease when the substrate thickness of a SIW horn antenna is reduced. The SIW horn antenna and the open space have significantly different impedances if the substrate's thickness is too thin. The impedance mismatch prevents SIW horn antennas constructed on thin substrates from their using at low frequencies.Many approaches have been attempted in order to obtain better impedance matching and improved performance of SIW-based planar H-plane horn antennas [1]–[4]. In [1], a transition printed on the same SIW substrate has been used to improve the matching performances with the thickness of substrate 0.086λ_0. A low profile ($\approx$ 0.028λ_0), quasi omnidirectional SIW H-plane multi horn antenna has been proposed in [2]. The antenna has achieved a fractional impedance bandwidth of 2.1% and the gain of 2.6 dBi. To improve the impedance matching between the horn aperture and free space, three shorting pins have been used in the thin substrates ($\approx$ 0.078λ_0 and 0.083λ_0) in a two different SIW H-plane horn antennas [3]. Recently, two new approaches have been studied to enhance the impedance bandwidth and gain of the SIW horn antennas [5], [6].

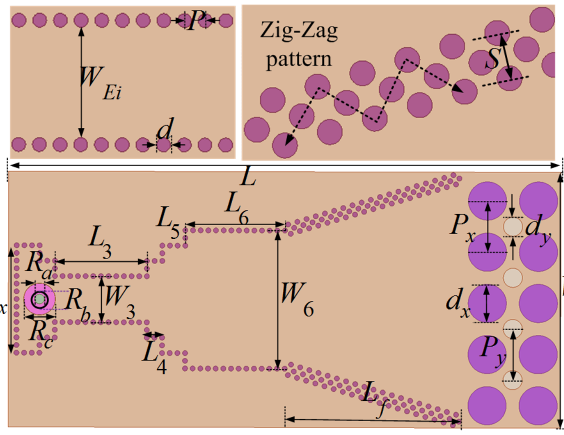
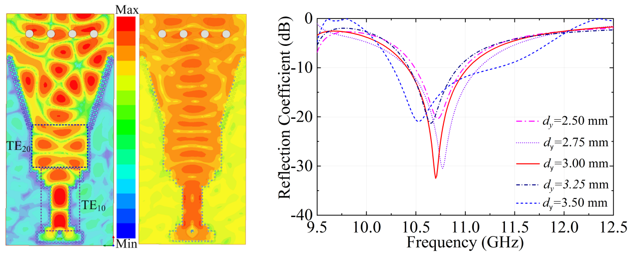


Fig. 1. The proposed antenna structure and dimensions.

This paper is demonstrating a low profile single-layer SIW-based H-plane horn antenna with high gain and improved performance parameters. In this design, three $\lambda_g/4$ transformers (λ_g: guided wavelength at 10.70 GHz) and four circular slots are used for impedance matching. Two rows of teflon vias are implemented around slots between the horn aperture and free space in order to enhance the peak realized gain without effecting the radiation efficiency. The designed antenna fabricated and also tested in the laboratory to cross-verify with the simulated results.

II. Antenna Structure and Dimensions

The top, enlarged part the waveguide section (top left corner) and enlarged corrugated wall flare SIW part (top right corner) views of the antenna are given in Fig. 1. Initially,



(a) (b)

Fig. 2. Electric field (left) and surface current (right) distributions at 10.7 GHz (a) and effect of d_y on the reflection coefficient (b).

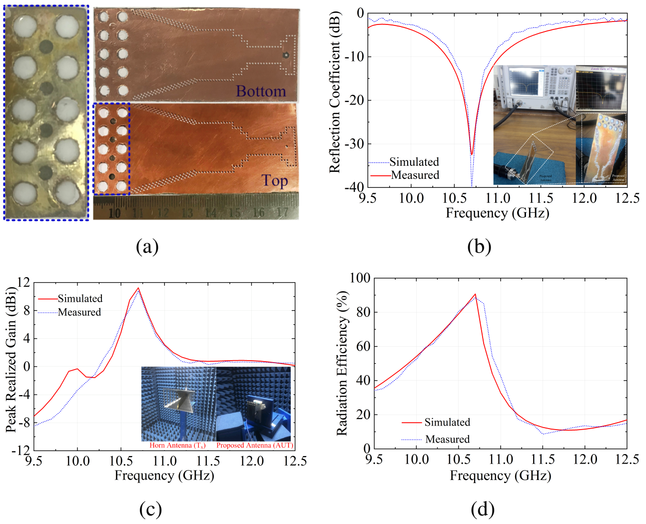


Fig. 3. Proposed antenna and simulated and measured results: (a) Fabricated prototype, (b) Reflection coefficient, (c) Peak realized gain, and (d) Radiation efficiency.

three stepped quarter wave transformers are used between two waveguide sections to provide better impedance matching. The first waveguide section (near feed) propagates TE_{10}, whereas the second waveguide section propagates TE_{20} (see Fig. 2 (a)). It is confirmed that the feed section provided the degenerated mode. Additionally, four circular slots are etched in front of the horn flare to improve the impedance matching and stabilizing other antenna characteristics. Moreover, two rows of teflon vias areset around slots between the horn aperture and free space. As a result, the horn gain is enhanced from 5.56 to 11.2 dBi. So, the radiation efficiency is decreased due to the loss in teflon. Simultaneously, the corrugated wall concept is implemented in the flare part. So. the radiation efficiency is stable without effects on enhancing the antenna gain. In order to fix the diameter of circular slots d_y, parametric analysis is used, as shown in Fig. 2 (b). The value of d_y=3 mm is providing the best impedance matching at 10.71 GHz. The dimensions of antenna are as follows: $P = 1.3$, $d = 0.8$, $S = 1.45$ $L_x = 17.6$, $R_a = 0.7$, $R_b = 0.9$, $R_c = 1.8$, $W = 41$, $L = 70$, $P_x = 8$, $d_x = 6$, $P_y = 8$, $d_y = 3$, $W_3 = 7.2$, $W_{Ei=3} = 6.67$, $W_6 = 21.6$, $W_{Ei=6} = 21.07$, $L_3 = 14.4$, $L_4 = 3.4$, $L_5 = 4.7$, $L_6 = 14.4$ $h = 0.25 = 0.009\lambda$; unit: millimeters. The substrate thickness is 0.25 mm, i.e., less than $0.009\lambda_0$ at 10.7 GHz. The structure was implemented with the Rogers RT Duroid 5880 (TM) material ($\varepsilon_r = 2.2$ and dissipation factor ($\tan\delta$)=0.0009). All the simulations were carried out using Ansys HFSS ver. 2020R2.

III. Experimental Verification

The top and bottom views of the fabricated antenna prototype are shown in Fig. 3(a). The simulated and experimental results of the reflection coefficient (RC) and the measurement setup with VNA are illustrated in Fig. 3(b). The measured fractional bandwidth (FBW) of 5.22% (simulated: 5.98%) is achieved. Fig. 3 (c) shows the experimental values of peak gains at 10.82 dBi (simulated: 11.26 dBi). Fig. 3(d) shows the measured radiation efficiency as 88.56% (simulated: 90.72%)

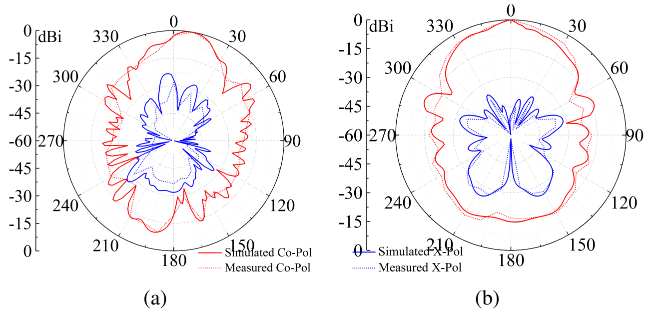


Fig. 4. Normalized radiation patterns: (a) E-plane, (b) H-plane at 10.71 GHz.

Table I
Comparison of Competitive and Proposed Antenna

Ref.	h (mm/λ_0)	FBW (%)	Gain (dBi)	η (%)	FTBR(dB)
[1]	1.524/0.086	16	7.1	NR	15
[2]	3.5/0.028	2.1	2.6	NR	NR
[3]	1.524/0.08*	1.3	5.7*	NR	2
This work	**0.25/0.009**	**5.22**	**10.82**	**88.56**	**≈15**

($*$): Average value, NR: Not reported

at 10.71 GHz. The measured and simulated normalized radiation patterns are plotted in Fig. 4. The FTBR of the H-plane is about 15 dB (simulated: 15 dB) at 10.71 GHz. Then, the measured cross-polarization level below -40 dB (simulated: -40 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 antenna.

IV. Conclusion

This paper proposes a low profile, high gain, low cross-polarization level, and high FTBR SIW-based H-plane horn antenna. The proposed antenna has operates in 560 MHz bandwidth (10.42-10.98 GHz) with the gain of 10.82 dBi. The efficiency of 88.56%, and the FTBR of about 15 dB have been achieved. This antenna can be suitable for X-band applications.

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