A Substrate Integrated Waveguide Based Antipodal Linear Tapered Slot Antenna for 60 GHz Wireless Communications

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Abstract **─** Antipodal linear tapered slot antenna (ALTSA) for 60 GHz communications is presented in this paper. To obtain a high gain, dielectric loading in addition to the corrugation structure is applied to the ALTSA. The use of substrate integrated waveguide (SIW) technology allows a highly efficient, compact and low cost planar design. The antenna is designed and simulated in an electromagnetic field simulation tool. To validate the proposed design, a prototype has been fabricated and measured. The simulated results agree well with the measured values, which validates the proposed design. The radiation efficiency is observed to be 92%. The antenna has a gain of 18.7 $\pm$ 0.5 dBi. The return loss is better than 10 dB over the 60 GHz band (57 GHz – 64 GHz).

Index Terms **─** Antipodal linear tapered slot antenna, dielectric loading, high gain, substrate integrated waveguide, 60 GHz.

I. INTRODUCTION

The ever-growing demand of high speed communication has made the unlicensed 60 GHz band (57 GHz–64 GHz) a smart option for wireless communication allowing transfer of uncompressed data, voice and video at the speed of multi gigabit per second (multi-Gbps) [1]. At millimeter wave frequency band, the losses in the planar microstrip circuit is high. Therefore, this requires more efficient technology like the substrate integrated waveguide (SIW) to be used, which has positive traits of traditional rectangular waveguide such as low loss, high quality factor, complete shielding and capability of handling high power along with the advantage of low cost and planar circuit design [2]. 60 GHz band also suffers from attenuation due to atmospheric absorption. This requires the use of high gain antennas to negate the losses. Tapered slot antennas (TSA) are famous for their high gain and wide bandwidth [3]. TSA with corrugation structure have been used for reducing the width of the antenna while minimizing any significant degradation in radiation pattern [3]. In [4], Shrivastava et al. have designed corrugated antipodal linear tapered slot antenna (ALTSA) with rectangular corrugation for 60 GHz band having the gain of 16 dBi at 60 GHz. Corrugation also increases gain and reduces side lobe level. Further, dielectric loading is also known for enhancement of antenna gain. By placing the dielectric slab in front of the antenna its gain can be increased. The dielectric slab in this case acts as a guiding structure [5] and enhances the gain of antenna. In [5], Ghassemi et al. have developed a high gain ALTSA array with SIW horn structure as the feed. Rectangular dielectric loading has been used to increase the gain of a non-corrugated ALTSA. In [5], the gain of single ALTSA is 14.25 dBi at 84 GHz and 1x4 ALTSA array is 19$\pm$1 dBi. In [6], Wang et al. have applied rectangle shaped dielectric loading structure to a planar SIW horn antenna and achieved a gain of 9.7 dBi at 27 GHz. In [7], Mohamed et al. have presented an ALTSA with diamond slot dielectric loading structure. The antenna has a gain of 16.2 dBi with a wide impedance bandwidth. In [8], Ramesh et al. have designed an exponentially tapered slot antenna (ETSA) with elliptical dielectric loading structure, which has a gain of 11.4 dBi at 60 GHz.

In this paper, instead of conventional elliptical shape, a rectangle with semicircular top shaped dielectric structure is used on a corrugated ALTSA to obtain a high gain antenna in the 60 GHz band. The antenna is designed and simulated in Ansys HFSS software.

II. ANTENNA DESIGN

The antenna is designed on Rogers RT/Duroid 5880 substrate which has dielectric constant of 2.2, loss tangent of 0.0009 and thickness of 0.254 mm. For proper design of SIW, the diameter of via holes and the space between the vias should be chosen as per (1) and (2) respectively:

$$D_{via} < \frac{\lambda_g}{5}, \quad (1)$$

$$S \leq 2D_{via}, \quad (2)$$

where λ_g is the guided wavelength, D_{via} is the diameter of the via and S is the space between the vias. The

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effective width of the waveguide is given by (3) [2]:

$$W_{eff} = W_{siw} - 1.08\frac{D_{via}^2}{S} + 0.1\frac{D_{via}^2}{W_{siw}}, \qquad (3)$$

where W_{eff} is the effective width, W_{siw} is the width of the SIW. The performance of TSA is sensitive to the thickness t and the dielectric constant ε_r. Hence, a factor $f_{substrate}$ is defined for efficient performance of TSA as $f_{substrate} = t(\sqrt{\varepsilon_r} - 1)/\lambda_0$ [3]. For good performance of tapered slot antenna, the substrate thickness should satisfy $0.005 \leq f_{substrate} \leq 0.03$. In this design we have chosen the substrate thickness of 0.254 mm such that $f_{substrate}$ is 0.024. ALTSA is generally designed with trial and error method. The width of the ALTSA is kept greater than 2λ [5]. The length of the flares is increased gradually until the optimum gain is achieved. Generally, the length varies from 3λ - 8λ to achieve the optimum gain. In this work, the optimum gain is observed when the length of the flares is 5λ. Firstly, the plain ALTSA is designed. Then corrugation is applied to the outer edges of the flares. Finally, a dielectric slab is added on top of the corrugated ALTSA to form the dielectric loaded ALTSA. The plain ALTSA (ALTSA-P), corrugated ALTSA (ALTSA-C) and corrugated ALTSA with dielectric loading (ALTSA-DL) are designed and simulated. Figure 1 shows the schematic of ALTSA-DL where L1 = 11.95 mm, L2 = 10.5 mm, L3 = 25 mm, L4 = 15 mm, L5 = 0.4 mm, W1 = 1.59 mm, W2 = 2.69 mm, W3 = 10.1 mm, W4 = W5 = 0.2 mm, r = 5.05 mm, V = 0.78 mm, D_{via} = 0.4 mm, S = 0.7 mm.

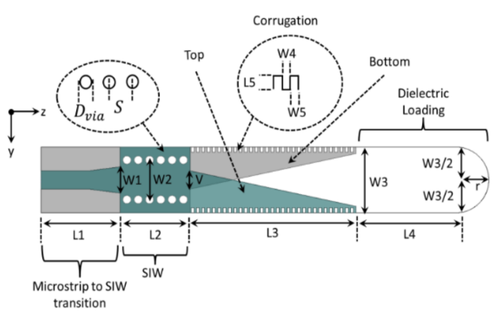

Fig. 1. ALTSA-DL schematic.

The structure of the dielectric load used in antenna has an impact on its gain. In this work, instead of a conventional elliptical dielectric loading structure, a rectangle with semi-circular top shaped design for dielectric loading is proposed. During simulation it is observed that rectangle with semicircular top shaped dielectric loading gives higher gain than conventional elliptical dielectric loading structure. The maximum difference in gain is observed to be around 0.76 dBi.

III. SIMULATION AND MEASUREMENT

Figure 2 shows the E-field distribution. The simulated gain and return loss of ALTSA are shown in Fig. 3. It is observed that return loss for ALTSA-P, ALTSA-C and ALTSA-DL are all better than 10 dB in the 60 GHz band (57-64 GHz). Also, it is observed that the return loss changes as corrugation and dielectric loading structure is added to the antenna. At 60 GHz, the ALTSA-DL has return loss better than 23 dB. Similarly, from Fig. 3 it is also observed that the gain of ALTSA-P, ALTSA-C and ALTSA-DL is 14.4 ± 0.3 dBi, 17.1 ± 0.3 dBi and 18.8 ± 0.6 dBi respectively. The simulated E-plane radiation pattern is shown in Fig. 4. In the E-plane the 3-dB beamwidth of ALTSA-P, ALTSA-C and ALTSA-DL is observed to be 22.6°, 19.5° and 17.5° respectively. Also, the side lobe level of ALTSA-P, ALTSA-C and ALTSA-DL in E-plane is observed to be at -13 dB, -15 dB and -17 dB respectively. Similarly, the cross polarization level of ALTSA-P, ALTSA-C and ALTSA-DL is observed to be better than 14 dB, 21 dB and 22 dB respectively.

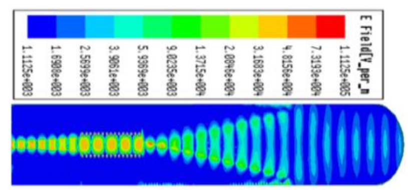

Fig. 2. E-field distribution in ALTSA-DL.

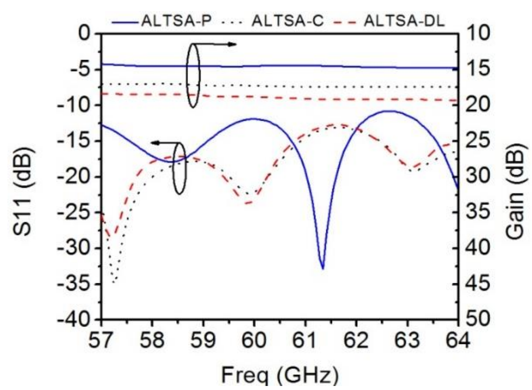

Fig. 3. Simulated return loss and gain.

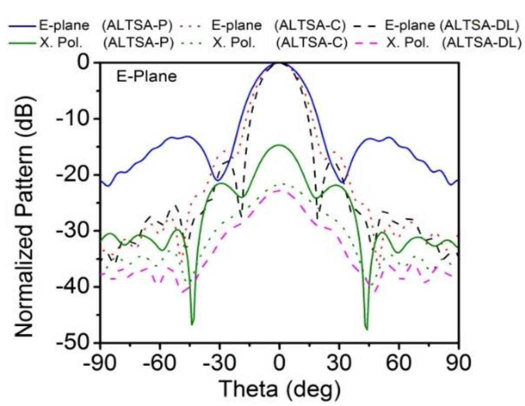

Fig. 4. Simulated E-plane radiation pattern at 60 GHz.

The simulated H-plane radiation pattern is shown in Fig. 5. The 3-dB beamwidth in the H-plane of ATLSA-P, ALTSA-C and ALTSA-DL is observed to be 29.5°, 33.1° and 25.2° respectively. Further, the side lobe level of ALTSA-P, ALTSA-C and ALTSA-DL in H-plane is observed to be -13 dB, -12 dB and -15dB respectively. Also, the cross polarization level of ALTSA-P, ALTSA-C and ALTSA-DL is seen to be better than 14 dB, 21 dB and 22 dB respectively. It is noted that, though with corrugation the E-plane beamwidth decreases but the beamwidth increases in H-plane. Overall it is found that ALTSA-DL has the narrowest beamwidth, lowest side lobe level and better cross polarization in both E- and H-planes. Therefore ALTSA-DL is found to have the best performance. Hence, ALTSA-DL is fabricated and its performance parameters are measured to validate the design.

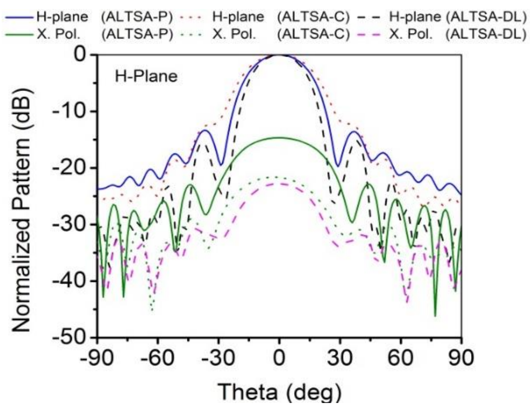

Fig. 5. Simulated H-plane radiation pattern at 60 GHz.

Figure 6 shows the fabricated ALTSA-DL prototype. The dimension of ALTSA-DL is 67.5 mm x 10.1 mm. It is compact in size and light weight. It is fabricated using the low cost printed circuit board (PCB) technology. The S11 parameters and gain of ALTSA-DL are measured utilizing MVNA-8-350 with probe station. The radiation pattern measurement has been performed in a far-field anechoic chamber.

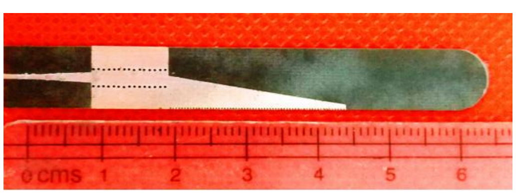

Fig. 6. Fabricated ALTSA-DL.

Figure 7 shows the measured gain and return loss of the ALTSA-DL. From Fig. 7, it is observed that measured gain of ALTSA-DL is 18.7± 0.5 dB over the entire 60 GHz band (57-64 GHz). The antenna gain is almost flat over the entire bandwidth. Similarly, measured return loss is observed to be better than 12 dB over the 60 GHz band. At 60 GHz, return loss is better than 22 dB. The discrepancy observed in the measured return loss with slight frequency shift can be attributed to the fabrication tolerances. Figure 8 shows the measured E-plane radiation pattern of ALTSA-DL at 60 GHz. The measured 3-dB beamwidth of ALTSA-DL in E-plane is 17° and the side lobe level is at -17 dB, which is similar to the values obtained from simulation. Similarly, Fig. 9 shows the measured H-plane radiation pattern of ALTSA-DL at 60 GHz. The measured 3-dB beamwidth of ALTSA-DL in H-plane is observed to be 22.7° and the side lobe level is at -15.7 dB. Further, it is seen that the simulated and measured radiation patterns are in good agreement in both E-plane and H-plane. Also, the radiation efficiency is observed to be 92%.

Table 1 lists the comparison with other SIW based antennas having different dielectric loading structures such as rectangle in [6], elliptical in [8] etc. It is observed that though the proposed antenna has less impedance bandwidth as compared to [7], its gain is better as compared to other antennas. Further, its impedance bandwidth covers 57-64 GHz, which is adequate for multi-Gbps communication at 60 GHz.

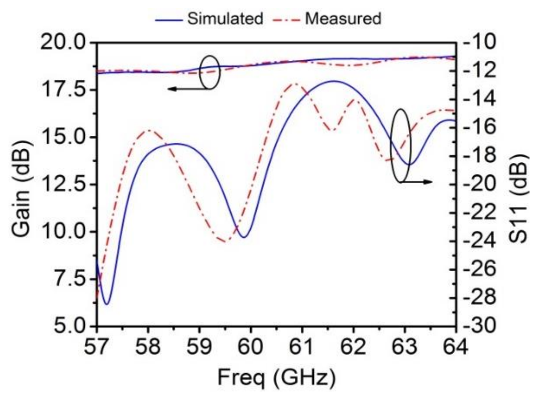

Fig. 7. Simulated and measured return loss and gain of ALTSA-DL.

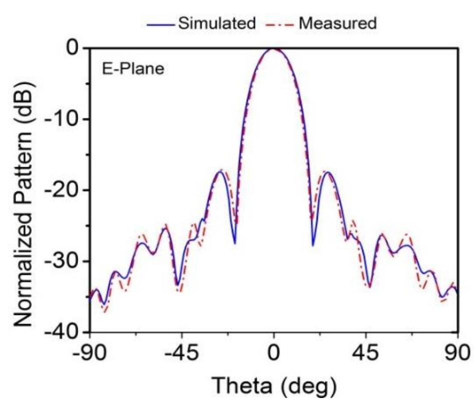

Fig. 8. Simulated and measured E-plane radiation pattern of ALTSA-DL at 60 GHz.

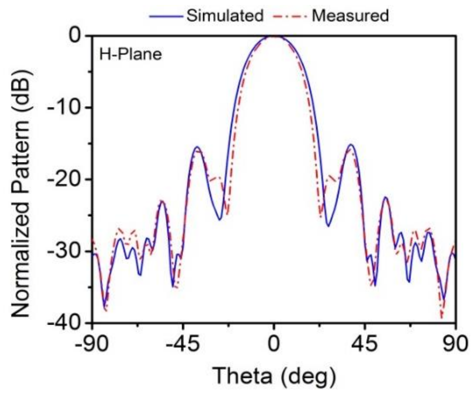

Fig. 9. Simulated and measured H-plane radiation pattern of ALTSA-DL at 60 GHz.

Table 1: Comparison with other antennas

Parameter	[6]	[7]	[8]	This Work
Antenna	Horn	ALTSA	ETSA	ALTSA
Dielectric loading structure	Rect.	Diamond slot	Ellip.	Rect. with semicircular top
Gain (dBi)	9.7	16.2	11.4	18.8
Impedance bandwidth	5.5%	33.3%	5.5%	11.6%
Operation frequency (GHz)	27	60	60	60

IV. CONCLUSION

A high gain ALTSA with dielectric loading is presented in this paper. The antenna has high gain, compact size, light weight, ease of fabrication using PCB technology and it is also fit for mass production. Hence, the proposed antenna is suitable for high speed communication in 60 GHz band.

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