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Broadband high-gain Linearly Tapered Slot Antenna with outside corrugations

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Abstract: This paper presents a high-gain antipodal linearly tapered slot antenna (LTSA) combined with substrate integrated waveguide (SIW) technique for Ku-band applications. The effects of periodic corrugation on the radiating elements are thoroughly investigated to optimize antenna performance. The periodic corrugation contributes to higher gain as well as and lower sidelobe level. The proposed antenna demonstrates broadband performance for frequency ranges from 13 GHz to over 17 GHz with gain of 16 dBi and relatively low cross-polarization levels of less than −25 dB. The 3-dB beam-widths of 36° in the H-plane and 22° in the E-plane have been obtained.

Keywords: corrugation, LTSA, tapered slot antenna

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Recently, there has been a great deal of interest in planar type antennas for millimeter-wave applications due to their excellent characteristics, such as lightweight, low profile, and easy to integrate with other planar devices. Conventionally, planar phased array antennas, Yagi-Uda antenna, LPDA (Log Periodic Dipole Antenna), and tapered slot antenna (TSA) have been widely used to take advantage of their high gain and low side-lobe level characteristics. Among them, the planar TSA is one of the most popular structures because of their ease of implementation, broadband characteristic and high element gain [1].

The TSAs has been studied for years. Main concerns of study are various type of tapered shape (Fermi, bunny ear) and various feeding structure [2, 3, 4]. However, there are limited reports on high gain TSA antennas. In this paper, a modified antipodal linear TSA with substrate integrated waveguide feeding structure is presented to achieve higher gain. Periodic corrugations on outside edges of the radiating elements contribute higher gain as well as lower cross-polarization level. In addition, broadband operation is achieved with the help of optimized overlap matching section, and better insertion loss performance is accomplished due to zigzagged via-hole arrangement on SIW structure.

2 Antenna design

Due to symmetric geometry of the tapered slot antenna, more symmetric radiation patterns in the E- and H-planes can be achieved compared to other planar antennas [1, 5, 6]. Fig. 1 depicts a configuration of the proposed antipodal LTSA, in which two linearly tapered radiating structures are placed on different side of PCB. Typical length of tapered slot line is $3\lambda_0$ to $8\lambda_0$. Width of the end of slot line is greater than $0.5\lambda_0$. In general, the directivity and beam-width of high gain endfire traveling wave antenna can be express

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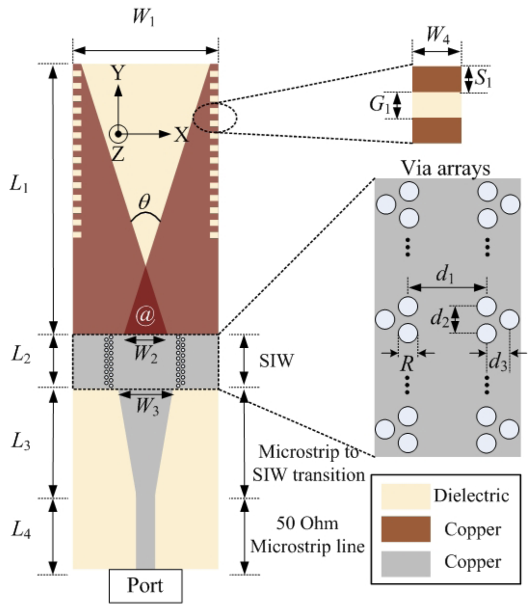

Fig. 1. Configuration of Proposed LTSA antenna (size $36 \times 146.4\,\text{mm}^2$).

as [7].

$$Directivity\ (dB) = 10\log\left(10\frac{L}{\lambda_o}\right) \tag{1}$$

$$Beamwidth\ (^\circ) = \frac{55}{\sqrt{L/\lambda_o}} \tag{2}$$

From Eq. (1), the length of radiating element mainly affects the gain of the antenna. It is clear that the gain of the antenna increases as the length of radiating element increases, but greater than some length, the gain does not increase anymore. According to previous researches, the maximum gain of 16 dBi to 17 dBi is achieved with $7\lambda_0$ to $8\lambda_0$ long radiating element [1, 6]. Generally, additional impedance matching network should be implemented because the input impedance of the LTSA is high and that of the SIW is low [4]. In this study, low input impedance of LTSA is achieved by partially overlapped section (shown as @ in Fig. 1). Thus, antenna is directly connected to the SIW section without additional matching network. To match the low characteristic impedance of SIW with $50\,\Omega$, linearly tapered additional microstrip section is used [8]. Proposed LTSA design parameters are: $W_1 = 36$ mm, $W_2 = 8$ mm, $W_3 = 9.6$ mm, $W_4 = 2$ mm, $L_1 = 90$ mm, $L_2 = 11$ mm, $L_3 = 30$ mm, $L_4 = 10$ mm, $d_1 = 11.8$ mm, $d_2 = 1.2$ mm, $d_3 = 0.8$ mm, $S_1 = 1$ mm, $G_1 = 1$ mm, $R = 0.6$ mm, and $\theta = 25°$. When the distance between via-holes d_2 (shown in Fig. 1) are electrically small ($d_2 < 0.2\lambda_0$), the SIW can be effectively considered as a rectangular waveguide [7]. The SIW can be commonly used as transmission line which is similar to rectangular waveguide in terms of mode and cutoff frequency properties. Assume that the distance of via-hole, d_1, represents the width of the rectangular waveguide a, while h refers to the height of the rectangular waveguide b. The height of substrate h should be much smaller than distance of via-hole

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d_1. Therefore, distance of via-hole d_1 determines the cutoff frequency of dominant mode of TE_{10}. Width of horizontal wall of the rectangular waveguide a, and cutoff frequency are given by [9].

$$a = d_1 - 1.08\frac{R^2}{d_2} + 0.1\frac{R^2}{d_1} \tag{3}$$

$$f_{c,mn} = \frac{c}{2\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \tag{4}$$

where c is the speed of light and ε_r is the relative permittivity of substrate. Zigzagged via-hole arrangement is adopted on SIW to reduce any undesired signal leakage which can be occurred on one via-hole arrays along the transmission line [10]. The propagation constant is calculated to confirm the pass band characteristic of designed SIW. The cutoff frequency of first mode (TE_{10}) is 8.8 GHz and that of second mode (TE_{20}) is 17.6 GHz. This characteristic verifies that the designed SIW can be utilized as a feeding structure for the proposed antenna from 13 GHz to 17 GHz with dominant mode operation.

3 Effect of corrugation

Corrugation structures are adopted on both sides of radiating elements to improve the radiation pattern [3]. Current distribution is examined to analyse the effect of corrugation structure. As shown Fig. 2 (a), current are mainly distributed both along the taper at the end of radiating element. Current distribution exclude tapered section of radiating element is caused radiation of unwanted direction which causes higher sidelobe and cross-polarization. Current path is arranged to be parallel and opposite in direction by placement of corrugation, thus helping to minimize the radiation toward the undesired direction (see Fig. 2 (b)). Fig. 2 (c) shows effects of corrugation structure compared with non-corrugation structure.

As a result, periodic corrugation structure contributes higher gain, low sidelobe level, and low cross-polarization level. In addition, the proposed antenna has been examined with different number of corrugation which increases from the end of antenna. Fig. 2 (d) shows that cross-polarization level and front-back ratio is proportionally decreased as the number of corrugations is increased up to 26 corrugations, while the sidelobe level remains almost unchanged.

4 Experimental results and discussion

All the simulations have been performed using Ansoft's High Frequency Structure Simulator (HFSS)$^{\text{TM}}$. The proposed antenna was designed on 0.75 mm thick Duroid substrate with dielectric constant of 2.5. The measurement was carried out on an Agilent's network analyzer (Model: E8364A).

To confirm the performance of feeding structure, back-to-back configuration of the SIW feeding structure is designed and measured. Results show that the return loss of greater than −10 dB and insertion losses less

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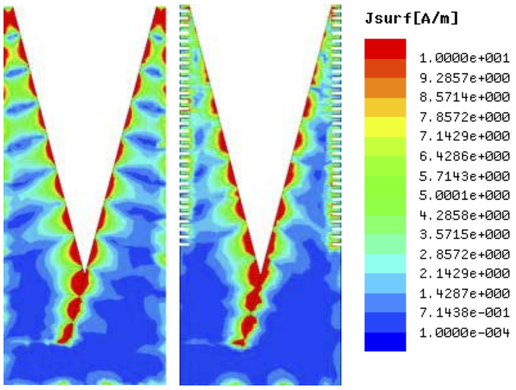
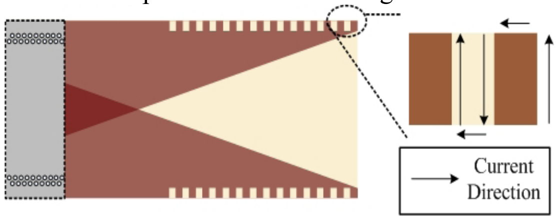
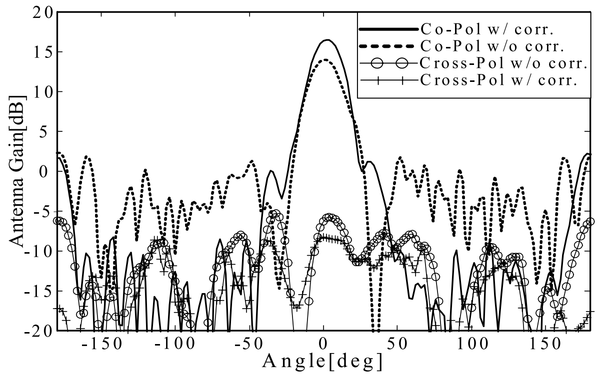


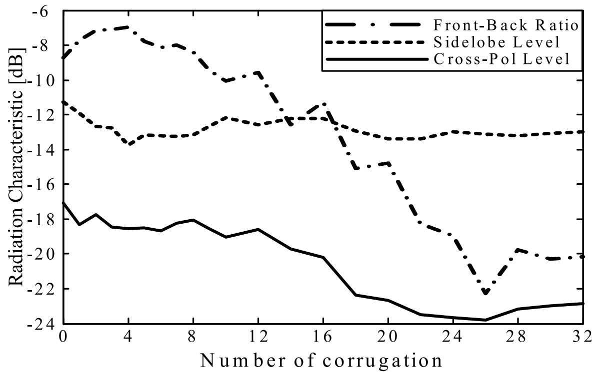
(a) Current distribution comparison between corrugation and non-corrugation structures



(b) Configuration of current direction at the edge



(c) Gain comparison (with and without corrugation)



(d) Effects of corrugation variation

Fig. 2. Effect of corrugation on the both side of antenna.

than 1.9 dB (0.95 dB for a single structure) over 13 GHz to 17 GHz region. Fig. 3 (a) shows the simulated and measured performance of the combined structure of the TSA and SIW, and shows return loss of greater than −10 dB over 13 GHz to 17 GHz. Fig. 3 (b) illustrates radiation patterns at two different frequencies of 14.5 GHz and 15.5 GHz. The measured and simulated results agree very well for entire operation band. The proposed antenna shows 15.9 dBi mainlobe gain, and cross-polarization level of −27.3 dB at 14.5 GHz,

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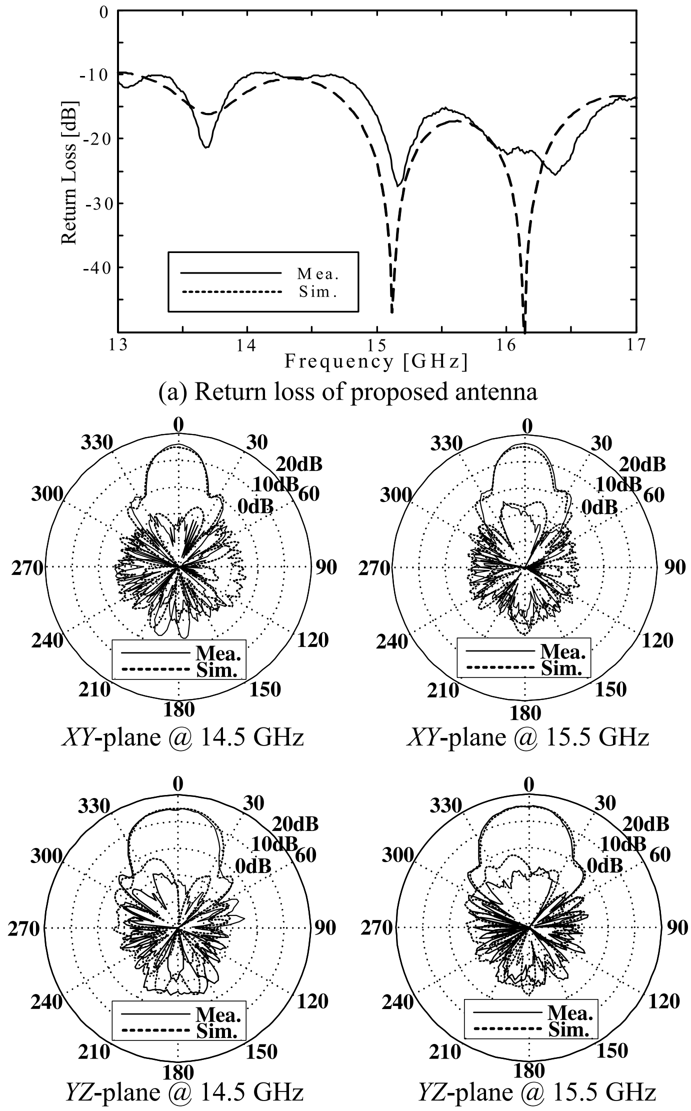

(a) Return loss of proposed antenna

(b) Radiation pattern of proposed antenna

Fig. 3. Simulated and measured results of proposed antenna.

and 16.9 dBi gain, and −24.1 dB of cross-polarization level at 15 GHz. And the gain of 17.2 dBi for co-polarization and −25.9 dB for cross-polarization level at 15.5 GHz have been achieved. 3-dB beam-width turns out to be 22° and 36° at each frequency for XY and YZ-plane, respectively.

From Eq. (1) and (2), the calculated gain and beam-width is 16.5 dBi and 26°. These results agree well with the measured results. It shows that the proposed antenna is optimized for the given design parameters. Gain of over 16 dBi with $4.5\lambda_0$ long radiating element is an excellent result which can be hardly obtainable with the TSAs. Although it is not shown here, 1×4 array is designed with combined structure of the proposed radiating elements and SIW power divider feeding network. Even further, the proposed array antenna reveals broad band operation capability over 13 GHz to 16.5 GHz with high gain of 21 dBi, very low sidelobe level of less than −11 dB, and cross-polarization level of less than −18 dB at 15 GHz. Although not shown here,

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in array antenna, SIW feeding structure has advantage of lower cross polarization compared to that of microstrip feeding structure because undesired radiation caused by discontinuities at bend section is suppressed. Moreover, the SIW structure shows lower insertion loss since it is based on waveguide feeding structure.

5 Conclusion

This paper presents a combined structure of SIW with TSA for Ku-band applications. Using periodic corrugation structure at the side of the antenna substrate, the gain and cross-polarization level characteristic has been greatly improved. The proposed antenna achieves broad bandwidth over 13 GHz to 17 GHz, high gain of greater than 16 dBi, and low cross polarization level of lower than −25 dB. The measurement results demonstrate that the proposed antenna can be a good candidate in the development of Ku band and millimeter-wave communication applications.

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