A SIW-CPW-fed high-gain antipodal Vivaldi antenna with elliptical dielectric lens

Fajian Zhen, Xingguang Li*
Department of Electronics and Information, Changchun University of Science and Technology, Changchun 130022, China
corresponding author’s e-mail: zfj513@mails.cust.edu.cn

Abstract: This paper proposes a Ka-band high-gain antipodal Vivaldi antenna. The antenna is designed by SIW-CPW power feed. Both ends of the radiating arm are loaded with elliptical patches, claw-shaped slots and rectangular corrugations are loaded on the patch, and elliptical lens are loaded on the front end of the radiating arm, and four rows of metal strips are loaded on the lens. The proposed antenna has overcome the shortcomings of the traditional Vivaldi antenna's high feed loss, and better improve the antenna gain. The Ka-band antenna shows excellent radiation performance, with a peak gain of up to 12.1dBi.

1. Introduction
As ultra-wideband technology is widely used in millimeter-wave detection radars, satellite communications and millimeter-wave imaging systems, millimeter-wave antennas are an important part of millimeter-wave systems, the demand for ultra-wideband, high gain, light weight and miniaturized planar millimeter wave antennas is increasing[1-3]. Among the planar antennas, the Vivaldi antenna has excellent performance such as wide bandwidth, medium gain, and symmetrical radiation pattern. It is one of the most promising antennas among many ultra-wideband antennas[4]. However, due to the high transmission loss in the millimeter wave frequency band, it is not easy for the Vivaldi antenna to achieve high gain and high transmission efficiency in a wide frequency range[5]. In order to reduce the impedance loss of the Vivaldi antenna and increase the antenna bandwidth and gain, Li Xiangxiang proposed the Ka-band SIW-GCPW-fed Vivaldi antenna in [5], with a gain greater than 5.8dBi; Jan Puskely used loading printing in [6] metal strip transitions and dielectric lenses improve the antenna gain, but the antenna length reaches 59mm; Farzaneh Taringou adopted SIW-CPW feed in [7], designed linearly tapered grooves at the radiating end, and loaded rectangular corrugations to expand the bandwidth and increase the gain. Unfortunately, in the 41-61GHz frequency band, the antenna length is greater than 45mm.

In this article, a Ka-band high-gain dielectric loaded antipodal Vivaldi antenna is proposed. In order to reduce the transmission loss and expand the antenna bandwidth, the antenna is fed by SIW-CPW, loaded with claw grooves and rectangular corrugations; in order to increase the antenna gain and control the antenna size, the radiating end is loaded with a dielectric lens, and the dielectric lens is regularly loaded metal strips. Section 2 introduces the design process of the antenna, Section 3 discusses the simulation results of the antenna, and gives a summary in Section 4.

2. Antenna Design
The antenna is designed on a Rogers RO5880 substrate with a thickness of 0.508mm, the dielectric
constant $\varepsilon_r = 2.2$, $\tan\delta = 0.009$, the thickness of the patch copper layer is 0.018mm, and the overall size of the antenna is $37 \times 15 \times 0.508\text{mm}^3$. The geometrical structure of the antenna is shown in Figure 1, and the dimensions of each part are shown in Table I.

![Figure 1. Antenna geometry structure diagram](image)

(a) Schematic  (b) Left-top layer, right-bottom layer

Table 1 The parameter of the designed antenna

| Parameter | mm | Parameter | mm |
|-----------|----|-----------|----|
| $W_c$     | 2.3| $L_t$     | 37 |
| $G$       | 0.1| $L_c$     | 4.7|
| $P$       | 0.8| $L_i$     | 16 |
| $d$       | 0.5| $L_r$     | 12 |
| $W_s$     | 7.33| $W_m$     | 0.5|
| $W_p$     | 0.65| $L_m$     | 3 |

Due to the high loss of the microstrip line and the limited bandwidth of the grounded coplanar waveguide, and the SIW loss at millimeter wave frequencies is an order of magnitude lower than the loss of the microstrip line, the CPW also has better flexibility in millimeter wave integrated circuits Sex. Therefore, here we choose SIW-CPW for feeding, SIW is connected to the antenna radiation patch for feeding, CPW is used as the input to connect to the active circuit, and the microstrip line is used for transition between SIW and CPW. The inner edge groove of the radiation patch is exponential, and the growth rate $\alpha$ is 0.2. The width of the inner edge groove is determined by the cut-off frequency, which is greater than $\lambda_c/2$. Inspired by [1], the loading of circular patches can expand the antenna bandwidth. In order to expand the bandwidth and increase the low-frequency end gain, this paper loads elliptical patch loads on both ends of the radiating arm, and loads claw-shaped slots and rectangular corrugations on the surface of the radiating arm to extend the current path and make the current approach the inner edge groove. The loading of the slots will reduce the gain of the high frequency band. To overcome this problem, an elliptical dielectric lens is loaded on the front end of the dielectric substrate, and the dielectric constant is consistent with the dielectric substrate. In order to avoid the phenomenon of further increasing the antenna size in [2], a compromise is made between antenna size and gain. We place four rows of metal strips on the dielectric lens to form a grating.

3. Simulation results and discussion

The designed antenna is simulated in HFSS. Figure 2 is a graph of the antenna reflection coefficient, using SIW-CPW for feeding and loading elliptical patches, which shows that the antenna has good impedance matching in the Ka-band. In terms of gain, as shown in Figure 3, by loading claw-shaped
slots and rectangular corrugations, the current is concentrated to the inner edge grooves, and the low-frequency end gain is increased to 10.2dBi, and the gain peak value is 12.1dBi at 32GHz; at the high-frequency end, the dielectric lens and metal grating are loaded, and the energy is concentrated at the dielectric lens for secondary radiation, so that the overall gain is greatly improved; and the radiation directivity is effectively/enhanced, as shown in Figure 4, which shows the antenna E plane and H at 30 GHz. The antenna radiation has good symmetry, and the sidelobe level is reduced. The E-plane 3dB beam width is less than 60°, and the H-plane beam width is less than 30°. Through SIW-CPW feeding, the combination of patch and slot is loaded, and a good matching impedance is obtained; The combination of slot, lens and grating improves the overall gain of the antenna, the main lobe of the pattern is concentrated, and the radiation performance is excellent.

4. Discussion

A Ka-band high-gain antipodal Vivaldi antenna is introduced. The antenna is fed by SIW-CPW, an elliptical patch load, a radiation patch composed of claw slots and rectangular corrugations, a radiation front end composed of a dielectric lens and a grating, so that the antenna exhibits excellent radiation performance in the Ka band. The proposed antenna is small and compact, and its excellent performance of ultra-wideband and high gain can be used as an alternative to millimeter wave imaging antennas in future work.
References

[1] A. Mirbeik-Sabzevari, S. Li, E. Garay, H. Nguyen, H. Wang and N. Tavassolian, "W-Band Micromachined Antipodal Vivaldi Antenna Using SIW and CPW Structures," in IEEE Transactions on Antennas and Propagation, vol. 66, no. 11, pp. 6352-6357, Nov. 2018.

[2] M. Moosazadeh and S. Kharkovsky, "A Compact High-Gain and Front-to-Back Ratio Elliptically Tapered Antipodal Vivaldi Antenna With Trapezoid-Shaped Dielectric Lens," in IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 552-555, 2016, doi: 10.1109/LAWP.2015.2457919.

[3] Z. Wang, Y. Yin, J. Wu and R. Lian, "A Miniaturized CPW-Fed Antipodal Vivaldi Antenna With Enhanced Radiation Performance for Wideband Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 16-19, 2016, doi: 10.1109/LAWP.2015.2425735.

[4] P. J. Gibson, “The vivaldi aerial,” in Proc. 9th Eur. Microw. Conf., Sep. 1979, pp. 101–105.

[5] X. Li, K. Xu, Y. Li, S. Ye, J. Tao and C. Wang, "SIW-Fed Vivaldi Array for mm-Wave Applications," 2019 IEEE International Conference on Computational Electromagnetics (ICCEM), Shanghai, China, 2019, pp.1-3.

[6] J. Puskely, J. Lacik, Z. Raida and H. Arthaber, "High-Gain Dielectric-Loaded Vivaldi Antenna for Ka-Band Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 2004-2007, 2016, doi: 10.1109/LAWP.2016.2550658.

[7] F. Taringou, D. Dousset, J. Bornemann and K. Wu, "Broadband CPW Feed for Millimeter-Wave SIW-Based Antipodal Linearly Tapered Slot Antennas," in IEEE Transactions on Antennas and Propagation, vol. 61, no. 4, pp. 1756-1762, April 2013, doi: 10.1109/TAP.2012.2232270.