An X-band Substrate Integrated Waveguide Vivaldi Array Antenna

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Abstract— In this paper, a kind of compact X-band Vivaldi array antenna printed on a substrate is proposed and designed. The antenna is consisted of 4 Vivaldi structure radiation elements fed by an equal power divider with substrate integrated waveguide technology. The Vivaldi element is antipodal structure composed with an index gradient microstrip line are on both sides of the substrate. The reflection coefficient of the substrate integrated waveguide Vivaldi array antenna is less than -10 dB from 8.9 GHz to 10.06 GHz in X-band. The gain of the array antenna is 14 dB, and the main lobe width is about 17.3° with side lobe level less than -12 dB.

1. INTRODUCTION

The Vivaldi antenna array has been used in many microwave engineering applications for its simple structure, light weight, wideband characteristics, low cross polarization, and highly directive patterns characteristics [1]. An equal power divider is necessary for the antenna array feed network with equal amplitude design. The substrate integrated waveguide (SIW) multi-way microwave power divider attracts a lot of attentions because of its advantages such as high Q-facter, small structural dimension, high integration and low cost [2–5]. A compact Vivaldi antenna array is printed on thick substrate, and it is fed by a SIW binary to significantly minimize the feed structure insertion losses [6]. A compact Vivaldi antenna array fed by a SIW structure is proposed, and four-elements printed Vivaldi array are designed and investigated in [7]. An eight elements antipodal Vivaldi antenna array using SIW technology is researched in [8], and it can reach a 12 dB gain at the center frequency of 10 GHz.

In this paper, a kind of Vivaldi array antenna printed on a substrate operating in X-band is designed and simulated. The antenna is consisted of 4 elements Vivaldi structure radiation fed by an equal SIW power divider. A Vivaldi element is antipodal structure composed with an index gradient microstrip line are on both sides of the substrate, and SIW-microstrip transition structure is designed to satisfy measurement and connection.

2. RADIATION ELEMENT DESIGH

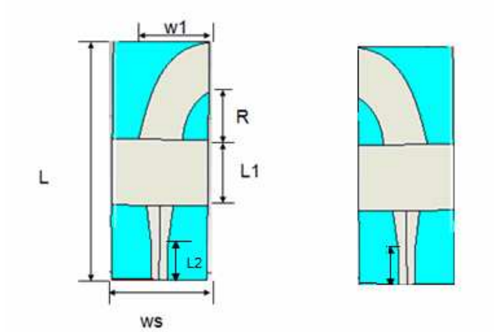
The antipodal Vivaldi radiation element is complementary structure are on both sides of the substrate. The antenna element is consisted of three parts in Figure 1. As shown in Figure 1, the upper part is the antenna radiator, the middle part is the connection structure, and the lower part is microstrip transition. The Vivaldi antenna is directly fed by a microstrip line. Impedance of the microstrip is equal to each export part of equal power divider. A SIW-microstrip transition structure is designed to satisfy measurement and connection. The transition section is taper microstrip line.

The inner part of antenna radiator part is part of an ellipse curve, and the outer is an index gradient curve whose exponential rate r is 1. The shape is determined by the following formula:

$$y = c_1 \times \mathrm{e}^{rz} + c_2 \quad (1)$$

As shown in Figure 1, w_s is an antenna width, L is the antenna length, L_2 set for the length of straight part in SIW microstrip transition, L_1 is the length of the connection part, R is length truncated by elliptic curve. The parameters of the Vivaldi radiation element is shown in Table 1.

The Vivaldi radiation element is simulated by CST MWS software. The reflection coefficient results are shown in Figure 2. It can be seen that the reflection coefficient is less than -12 dB at 8.5 GHz to 10.5 GHz. The pattern of the antipodal Vivaldi antenna is shown in Figure 3, the gain can reach 3.85 dB. The back lobe in H-plane pattern can be greatly improved after cut down part of the antenna radiator. The side lobe level is lower, while the back lobe level reduced 1.1 dB after cut down part of the antenna radiator portion along ellipse.



(a) Upper part (b) lower part

Figure 1: Antipodal Vivaldi antenna element.

Table 1: Parameters of the Vivaldi antenna element.

parameters (mm)	w_1	R	L	L_1	L_2	w_S
	8.35	6.2	30.37	8.2	17	11.4

3. FOUR-WAY SIW POWER DIVIDER

A SIW is composed with two column metallized via holes in the dielectric substrate and upper and lower metal layers. A kind of similar rectangular waveguide structure is composed by via hole and two metal layers. The characteristics of electromagnetic wave transmission in SIW is similar with the characteristics in metal waveguide. For integration with coplanar waveguides or microstrip circuits, a transition structure should be designed to satisfy measurement and connection. The electromagnetic field of the microstrip line is similar to the TE_{10} mode of the substrate integrated waveguide. The general SIW-microstrip transition is a section of taper microstrip line in Figure 4. The taper line is able to realize impedance transformation between the $50\,\Omega$ microstrip line and the substrate integrated waveguide.

Ordinary Y-shaped structure can be achieved the power divisions, however its discontinuous structure is able to result in the higher return loss in pass band. The metal pin in SIW can reduce the power reflection. The electric field distribution of the Y-junction is able to be changed by surface current distribution of the metal pin inductance.

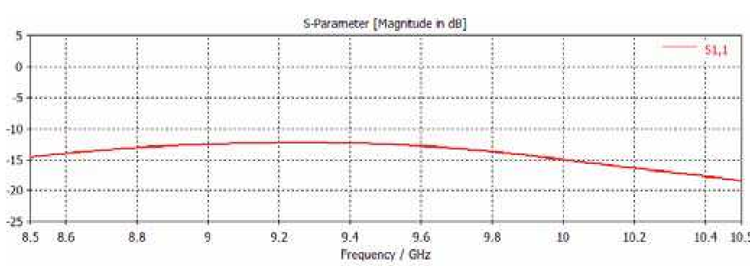
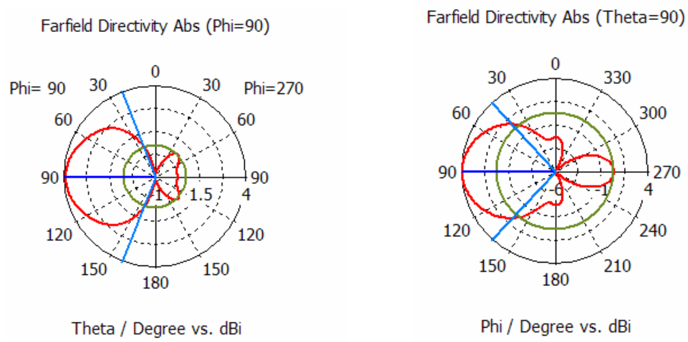


Figure 2: Reflection coefficient of the Vivaldi antenna element.

Table 2: Parameters of the 4-way SIW power divider.

parameters (mm)	a	p	D	h_1	h_2	h_3	D_1
	12	1	0.6	4	17	17	0.5
parameters (mm)	D_2	D_3	D_4	R	L_2	w_s	w_2
	0.5	0.6	0.3	6.2	4.5	11.4	5.5
parameters (mm)	t_2	t_3	t_4	w_4	w	w_1	t_1
	5	5	7	5	2	8.35	4.9



(a) E-plane pattern (b) H-plane pattern

Figure 3: Pattern of the Vivaldi antenna element.

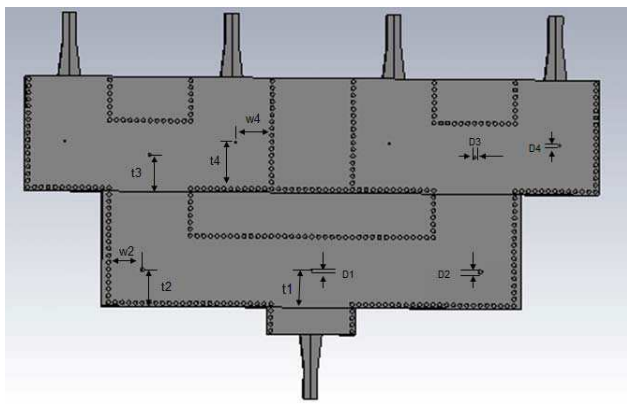


Figure 4: 4-way SIW power divider.

The reflection coefficient can be significantly reduced by adjusting diameter and position of the pin in SIW, which can influence the distribution of the electric field. The parameters of the four way SIW power splitter are shown in Table 2.

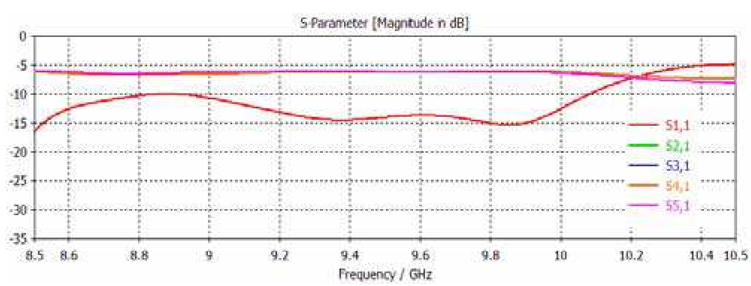
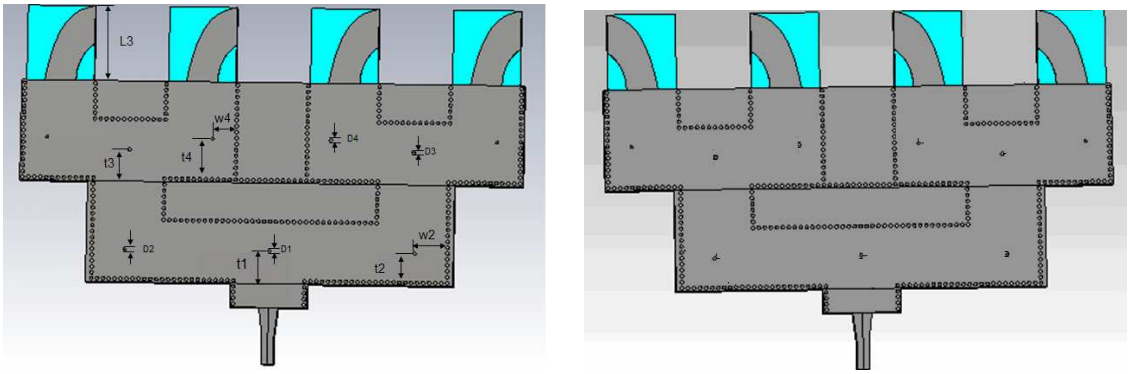


Figure 5: S parameters of the 4-way SIW power divider.

In the Table 2, a is the distance between the antenna, p is the distance between two vias in vias array, D is the diameter of the vias, h_1 is the width of the connection structure, h_2 is the width of the first section of Y-junction structure, h_3 is the width of the second Y-junction structure, Z_1 is the thickness of the medium, Z_2 is the thickness of PEC in simulation.

To be convenient to test by coaxial cable, five SIW micro-strip transitions are needed to connect with SIW power splitter. The 4-way SIW power divider is simulated by CST MWS software. The simulation S parameters results of different ports are shown in Figure 5.

It can be seen that the reflection coefficient is less than -10 dB at 8.5 GHz to 10.5 GHz. The transmission coefficients, such as S_{21}, S_{31}, S_{41}, S_{51} parameters, are almost reach about -6 dB, and they are substantially coincident to achieve the power divisions.



(a) Upper part (b) lower part

Figure 6: Simulation model of the antipodal Vivaldi antenna array.

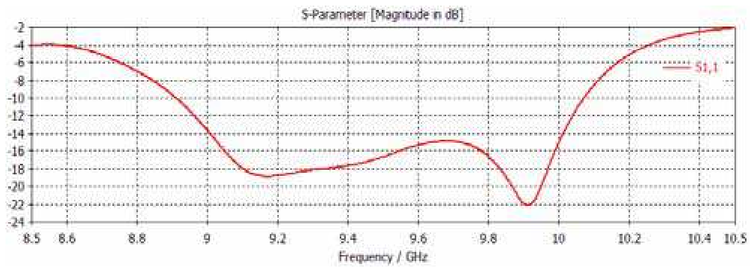
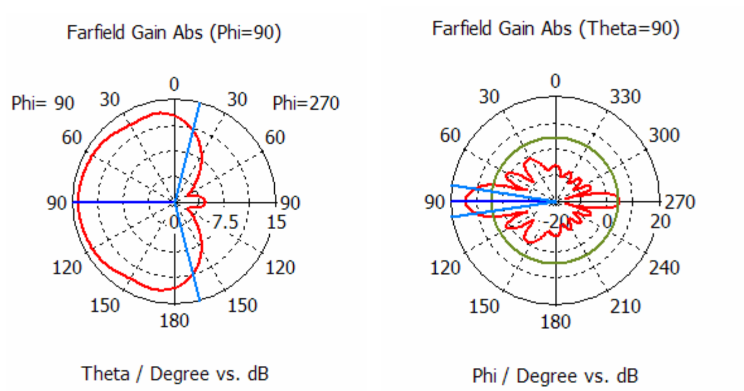


Figure 7: Reflection coefficient of the antipodal Vivaldi antenna array.



(a) E-plane pattern (b) H-plane pattern

Figure 8: Pattern of the antipodal Vivaldi antenna array.

4. ANTIPODAL VIVALDI ANTENNA ARRAY

The last simulation model of antipodal Vivaldi antenna based on 4-way SIW power divider is shown in Figure 6. The pin is placed in center of a quarter SIW waveguide wave lengths, then it is optimized to get the best value of r values. Due to the design of the previous step has been made in better results, t_1 need to be tuned, making the minimum point of the reflection is located in the center of the frequency band as should be designed. The length of Vivaldi antenna element is $L_3 = 12.67$. The design of the dielectric substrate using a relative permittivity $\varepsilon_r = 4.5$, dielectric thickness $h = 1.6$ mm.

The 4-element antipodal Vivaldi antenna array is simulated by CST MWS software. The simulation results are shown in Figure 7. It is shown that the S_{11} parameter is less than -10 dB from 8.9 GHz to 10.07 GHz. The radiation pattern of the antenna array is shown in Figure 8. As shown in Figure 8, the array gain reach 14 dB. And and the main lobe width is about 17.3° with side lobe level less than -12 dB.

5. CONCLUSION

The planar Y-junction multi-way power distribution with metal pin technology is used in the 4-way SIW equal power divider, and the impedance characteristics and transmission characteristics satisfies the Vivaldi antenna array design. The Vivaldi radiation element is consisted of the antipodal structure. An element is composed with an index gradient microstrip line are on both sides of the substrate. The operating frequency of the SIW Vivaldi array antenna is more than 1.1 GHz in X-band. The gain of the array antenna is 14 dB, and the main lobe width is about 17.3° with side lobe level less than −12 dB.

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