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IMPROVEMENTS IN A 4-ELEMENT HIGH GAIN DIRECTIONAL UWB ANTENNA ARRAY

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Abstract—In this paper, a novel serrated structure at the edges of the antipodal Vivaldi antenna is introduced. Compared with the Vivaldi antenna without serrated structure, the novel structure antenna has a better Front-to-Back ratio (F/B ratio). Additionally, when building a 4-element array with mirror image elements placed alternately along the *H* plane, the cross-polarization level at the boresight is reduced a lot compared to conventional array configuration. The design of the novel 4-element Vivaldi antenna array with mirror image elements described in this paper experimentally produces a gain with a range of 9∼15 dBi, F/B ratio more than 15 dB, and cross-polarization level at the boresight is reduced more than 10 dB from 3.5 GHz to more than 10.6 GHz with −10 dB return loss. The novel antenna array can be used for directional UWB systems.

1. INTRODUCTION

Since the Federal Communication Committee (FCC) allocated 3.1 ∼ 10.6 GHz for civil use in February 2002, much research has been focused on the design of high gain ultra wide band (UWB) antennas [1–4]. Compared with other kinds of UWB antenna, an antipodal tapered slot antenna (ATST), especially the antipodal Vivaldi antenna, is suitable for high gain directional UWB antenna for its small volume, light weight, and easy fabrication.

The Vivaldi antenna undergoes many improvements in the last three decades, including introducing corrugated edges to form a better radiation pattern [5, 6], because the corrugated structure alters the phases of currents flowing along the outer part of the substrate, and changes the direction of the electric field at the edges of the antenna

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substrate [7]. To achieve high gain, good F/B ratio and ease in design and fabrication, a new serrated structure at the edges of the Vivaldi antenna is designed and analyzed.

For some long distance communication and radar applications, directional UWB antennas with high gain are needed in order to enhance the quality of communication link and transmission range. One solution is the usage of antenna array [8]. So the Vivaldi antenna array consisting of many elements along the H plane is used to increase the gain and steer the beam in the H plane, but it also increases the cross-polarization level both in E and H planes [9, 10]. A simple technique to reduce the cross-polarization level is mentioned in paper [9], in which mirror image elements placed alternately along the H plane can cancel out the unwanted cross-polarized fields at the boresight.

In this paper, the performance of the antenna array is improved by using serrated structure and building a 4-element array with mirror image elements placed alternately along the H plane. The performance of the improved antenna array and important parameters are investigated both numerically and experimentally.

2. DESIGN AND ANALYSIS OF ANTENNA ARRAY

2.1. Design and Analysis of Antenna Element

The proposed antipodal Vivaldi antenna structure is show in Figure 1. The antenna is designed to fabricate on a low-cost F4B-2 substrate,

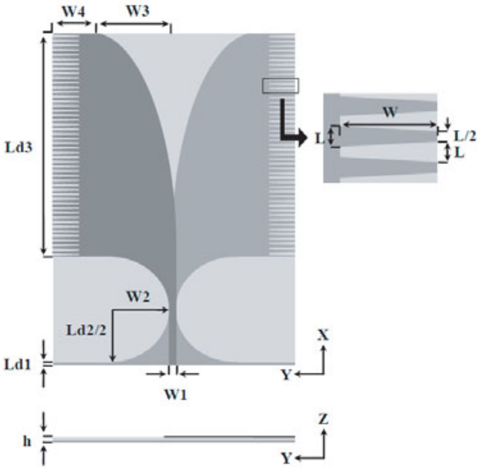


Figure 1. The structure of the antenna.

with relative permittivity 2.65 and loss factor 0.009. The reason that we choose it is its low cost and light weight. If we choose expensive dielectric substrate with higher relative permittivity, the size of the antenna will be smaller while the gain will be higher with the same impedance bandwidth.

This antenna is fed by a microstrip line through a parallel-strips transition, while the end of the microstrip is soldered with a SMA connector. As the performance of the Vivaldi antenna is sensitive to the width of microstrip line (W_1), the length of the ground (L_{d1}) and the structure for translation, we use some elliptical arc structures for wideband translation. The microstrip on the top of the substrate uses a quarter elliptical arc, while the one on the ground plane uses a quarter elliptical arc and a half elliptical arc, so the lengths of the elliptical arc are also critical to the translation function.

The main radiation structure is two pieces of antipodal quarter ellipse (the major and minor axes are L_{d3} and W_3 respectively) with their rectangular patch (length and width are L_{d3} and W_4 respectively) additionally. One piece of the top quarter elliptical patch produces one half of the conventional Vivaldi antenna, and the other piece on the ground plane is antipodal to the top, which form a Vivaldi antenna with two wings on different sides of the substrate.

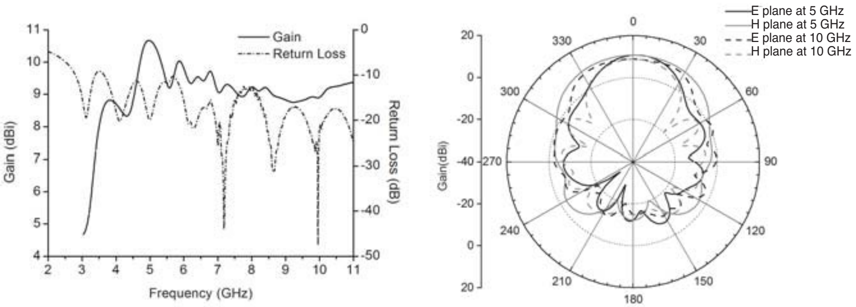
As mentioned above, the corrugation structure can improve the radiation pattern. So some periodic serrated slits are added at both edges of antipodal Vivaldi antenna. As shown in Figure 1, the shape of the slits are isosceles trapezoids, with $3/2L$ period. Compared with the corrugated structure antenna in [7], the proposed serrated structure has only one single length, so it simplifies our design a lot while the F/B ratio has been also improved.

We tried massive numerical calculations in Ansoft High Frequency Structure Simulator (HFSS) and CST Microwave Studio Package to satisfy our requirements of the antenna with low return loss, high gain, narrow beam width and less backward radiation in the frequency range of $3.1 \sim 10.6$ GHz, then we get a set of geometric parameters listed in Table 1. Figure 2 shows the calculated return loss and the radiation patterns of the proposed antenna. It is noticed in Figure 2(a) that the boresight gain of the proposed antenna is between $5 \sim 11$ dBi with the return loss less than -10 dB from 3 to 11 GHz which

Table 1. Geometric parameters of the antenna.

W_1	W_2	W_3	W_4	L_{d1}	L_{d2}	L_{d3}	h	W	L	Unit
2	18	25	11.5	1	32	68	1	7.5	1	mm

covers the UWB band totally. It is demonstrated that the serrated structure at the edges of the antipodal Vivaldi antenna has a good F/B ratio in Figure 2(b). In Table 2, there are the calculated radiation characteristics of the antenna without serrated structure (slits) and the antenna with serrated structure ($L = 1\,\text{mm}$, $W = 7.5\,\text{mm}$). It is obvious that most of the radiation characteristics are the same, while the latter has a better F/B ratio, which is 10 dB more than the former.



(a) (b)

Figure 2. (a) Return loss and boresight gain vs. frequency. (b) Radiation patterns of the antenna (solid lines: 5 GHz, dash lines: 10 GHz).

Table 2. Radiation characteristics of the antenna without slits vs. those of the antenna with slits.

	Antenna without slits				Antenna with slits			
	5 GHz		10 GHz		5 GHz		10 GHz	
Plane	*E*	*H*	*E*	*H*	*E*	*H*	*E*	*H*
Main lobe gain/dBi	8.3	8.3	9.3	9.1	10.7	10.6	8.8	8.8
Main lobe direction/deg	93	90	85	90	93	90	109	90
3 dB angular width/deg	49.7	81	63	44	35	79	71	42
Front-to-back ratio/dB	11	11.5	14	14	23	23	24	24
Side lobe level/dB	−7.7	−9.6	−6.9	−14.1	−14	−14	−9.2	−12.8

2.2. Design and Analysis of 4-element Antenna Array

The calculated gain along the boresight of a single antenna from 3 $\sim$ 11 GHz is presented in Figure 2(a). The gain through operating bandwidth is a range of 5 $\sim$ 11 dBi. It is noticed that when frequency is in the range of 5 $\sim$ 11 GHz, the antenna gains are around 9 $\sim$ 11 dBi, which means the antenna has a moderate gain from 5 $\sim$ 11 GHz. In order to enhance the antenna gain and steer the beam while considering the area of the antenna array, we compose 4 identical Vivaldi antennas with serrated structure edges which are stacked along the H plane (along Z axis) for UWB array, instead of stacking along the E plane. As mentioned above, mirror image elements are placed alternately, which can cancel out the unwanted cross-polarized fields. So we tried two kinds of antenna arrays in our calculation. Figure 3 shows the two array configurations.

In our calculation for comparing the radiation patterns of the two arrays, the separation d between the two adjacent antenna elements is kept the same for both antenna array configurations. Figure 4 shows the calculated antenna radiation patterns of the two array configurations, when the separation d is 20 mm. As shown in Figure 4, by introducing the mirror image elements along the H plane, the cross-polarization level at the boresight in the E plane is 10 dB better than those of the conventional array, 20 dB better in the H plane. It is noticed that the cross-polarization level is reduced almost 10 dB of all directions in the E plane not only at the boresight. And it is also noticed that the F/B ratio of the mirror image elements antenna arrays is 20 dB and 30 dB at 5 GHz and 10 GHz, respectively. It demonstrates that the proposed antenna array has a good performance of high gain, good F/B ratio and low cross-polarization level.

In order to achieve a better radiation pattern, we also tried a set of array elements spacing d for the 4 mirror image elements array in

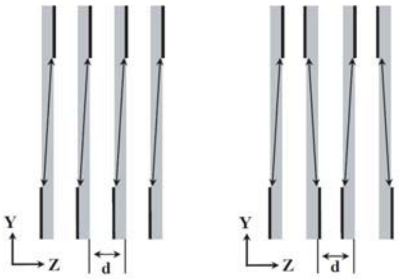


Figure 3. Two configurations of 4-element antenna array. (The left one is the conventional array, the right one is the mirror image elements array).

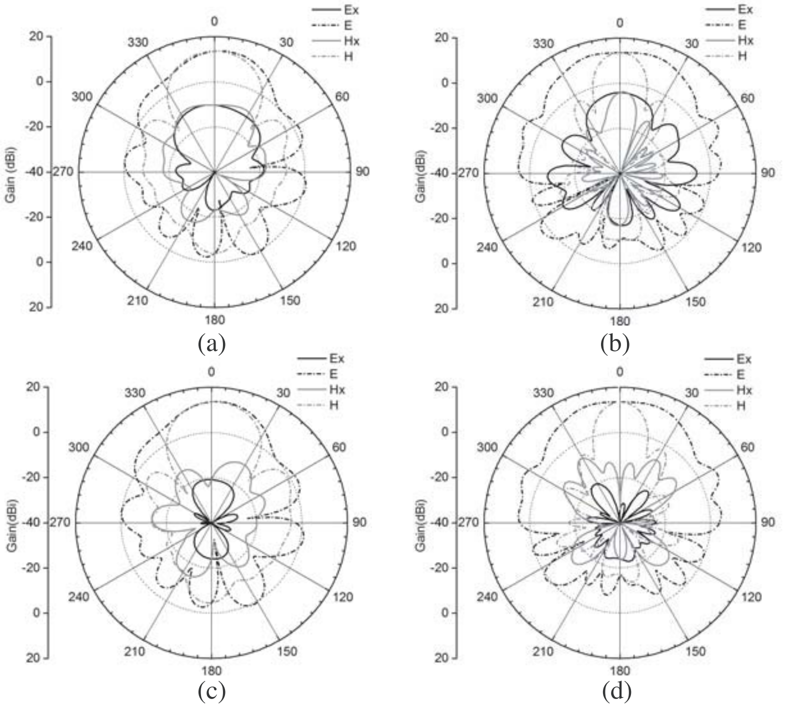
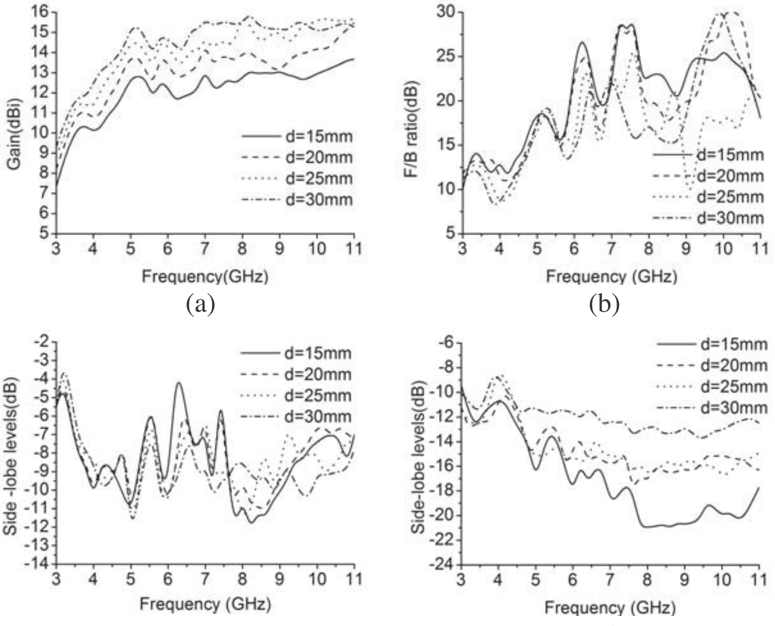


Figure 4. Radiation patterns of conventional array at (a) 5 GHz, (b) 10 GHz, Radiation patterns of mirror image elements array at (c) 5 GHz, (d) 10 GHz.

our calculation, because the gain and radiation pattern of the antenna array are critically dependent on the separation d between the two adjacent mirror image elements. Figure 5 illustrates the calculated radiation characteristics of the 4 mirror image elements array for different d values. It is noticed that as d increases, the boresight gain increases. It also increases with the increase of frequency, and the range of it remains 2 dB between $5 \sim 11$ GHz for all d values. For different d values except $d = 25$ and $d = 30$, the F/B ratio is more than 10 dB over the impedance bandwidth, and when $d = 15, 20$, the fluctuation of it is less than other d values. In the E plane, the side-lobe level fluctuates over the operational frequency range for all d values, but it remains lower than -4 dB; the range of fluctuating decreases with the increase of d. In the H plane the side-lobe level decreases as frequency increases, below -8 dB over the operational frequency range. But as d increases, the side-lobe level increases a lot. As a compromise among these radiation characteristics, $d = 20$ mm is relatively a better choice.



(a) (b)

(c) (d)

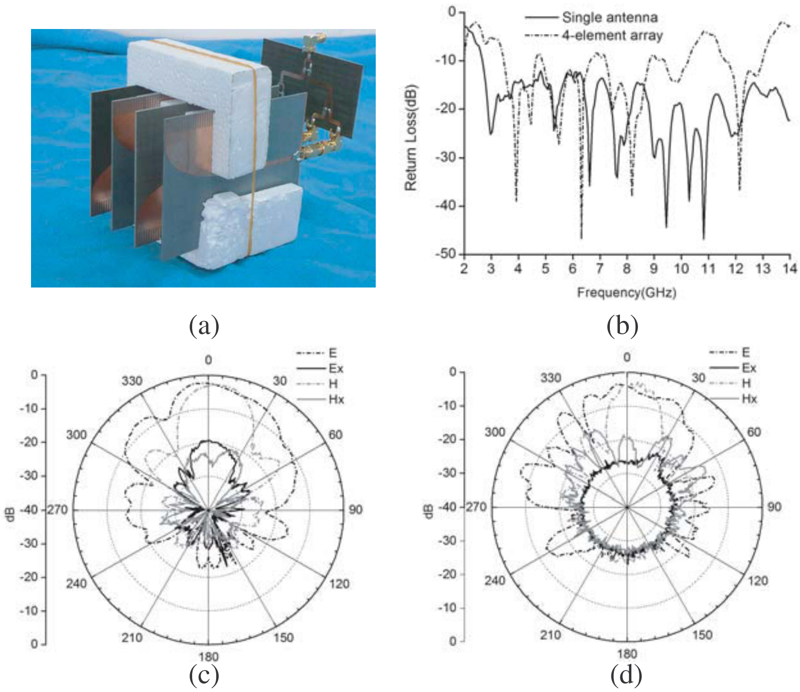
Figure 5. (a) Boresight gian vs. frequency for different d. (b) F/B ratio vs. frequency. Side-lobe level vs. frequency for different d in the (c) E plane, (d) H plane.

3. MEASUREMENTS

An antenna array including the power divider with the element separation of $d = 20\,\mathrm{mm}$ was built to verify the calculated results. Figure 6(a) shows the prototype of the antenna array. The return loss was measured using an Agilent N5230A vector network analyzer, and the radiation pattern measurements were carried out in the anechoic chamber of Sichuan University. The measured results are plotted in Figures 6(b)–(d).

As shown in Figure 6(b), the measured return loss curve of single antenna remains lower than −10 dB from 2.6 GHz to more than 14 GHz. And the measured −10 dB bandwidth of the antenna array can cover most range of the UWB band, which is from 3.5 to more than 10.6 GHz. For some unknown reflections and the impedance bandwidth limitation of the power divider, it is obvious that the lower frequency of antenna array is higher than that of single antenna.

As shown in Figures 6(c), (d), the measured radiation patterns agree well with the calculated ones both in the E and H planes for the two frequencies. But it is difficult to achieve the same results in measurements due to the slightly asymmetrical setup and some uncertain reflections. It is clearly noticed that the measured F/B ratio and cross-polarization level are better than the calculated results, the F/B ratio is greater than 20 dB in both *E* and *H* planes, and the cross-polarization level at the boresight is almost −20 dB in both *E* and *H* planes at 5 GHz and 10 GHz.



(a) (b)

(c) (d)

Figure 6. (a) The photograph of the antenna array. (b) Measured return. (c) Normalized measured radiation pattern at (c) 5 GHz, (d) 10 GHz.

4. CONCLUSION

An antipodal Vivaldi antenna is an important aspect of the research of high gain directional UWB antenna due to its relatively good impedance bandwidth and radiation pattern, but unfortunately the F/B ratio is dissatisfactory and the cross polarization level is high. This paper starts from a single simple Vivaldi antenna element with serrated structure edges. The F/B ratio of which is more than 15 dB with the impedance bandwidth from 3 GHz to more than 11 GHz. Then, the antenna array gain of 9 $\sim$ 15 dBi in the range of 5 $\sim$ 11 GHz is obtained while the cross polarization level at the boresight is reduced more than 10 dB by placing mirror image elements alternately along the H plane. It has been proved experimentally that the proposed antenna array is very suitable for directional UWB systems.

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