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IMPROVEMENTS IN A HIGH GAIN UWB ANTENNA WITH CORRUGATED EDGES

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Abstract—In this paper, a novel corrugated structure at the edges of the Vivaldi substrate is presented. Compared with the Vivaldi antenna without corrugated structure, the new structure has a better radiation pattern. While compared with the traditional corrugated structure, the new structure has a better front-to-back ratio (F/B ratio). Properly chosen thickness and dielectric constant of substrate ensure a relatively small size while the lower frequency is around 1 GHz. A Vivaldi structure also promises high gain in ultra-wideband (UWB) range. For its planar structure, the antenna is easily fabricated with a low cost. The design of a novel Vivaldi antenna described in this paper operates from 1 GHz to more than 3 GHz with -10 dB return loss and produce the gain with a range of 7 dBi $\sim$ 11 dBi. The current design is one of the most ideal antennas to be used for through-wall radar.

1. INTRODUCTION

The through-wall radar has been given great attention in the past few years, for its promising use in military and anti terrorist action. If the activity of enemies or terrorists behind the wall is known, the action is more likely to be successful and number of casualties will decrease.

Through-wall radar may use two kinds of signal: ultra-wideband (UWB) signals and pulse Doppler signals [1–3]. The latter can only detect moving targets, while UWB signals can detect both static and moving targets, with high spatial resolution.

For through-wall radar with UWB signals, the antenna should satisfy a few characteristics:

1) High gain to cross the wall

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2) Enough bandwidth
3) Small size for portable use
4) Narrow lobe width
5) Easily connected to transceiver

Both Vivaldi antenna and ridge horn antenna have a wide bandwidth and high gain. However, ridge horn antenna have several disadvantages: 1) hard to be fabricated; 2) high cost; 3) relatively big volume; 4) need UWB balun to connect to coaxial cable. Compared with a ridge horn antenna, a Vivaldi antenna has smaller volume and weight, also easier to fabricated, so it is more portable.

The Vivaldi antenna has been studied since its first appearance in 1979 [4]. It undergoes many improvements in the last three decades, including introducing corrugated edges to form a better radiation pattern [5, 6], or changing beam width by changing the shape, length, dielectric constant, and dielectric thickness. As one of the improvements, antipode Vivaldi antenna was proposed [7, 8]. Very wide band performance can be acquired using an antipodal Vivaldi antenna with its easy wideband transition from microstrip line to radiation part of the antenna [9, 10].

The corrugated structure can improve the radiation pattern, because the corrugated structure alters the phase of currents flowing along the outer edges of the substrate, and changes the direction of the electric field at the edge of the antenna substrate [5]. In this paper, a novel corrugated structure at the edges of the Vivaldi substrate is presented.

Compared with the traditional corrugated structure, the new structure (Fig. 1) has a better F/B ratio. The improvement of the F/B ratio is very important to through-wall radar. The antenna operates from 1 GHz to more than 3 GHz and produces gain with the range of 7 dBi $\sim$ 11 dBi.

2. HIGH GAIN UWB ANTENNA DESIGN

2.1. Antenna Structure

The antenna is designed to be fabricated on a low-cost FR4 substrate, the thickness of which is 1.6 mm. We chose a value of 4.5 as the relative permittivity of the dielectric in the simulation. If we select higher relative permittivity dielectric, the size of the antenna will be smaller while possessing similar requirements.

In the purpose of connecting to the transceiver easily, there is a part of microstrip line in the antenna, while the end of microstrip line is soldered with a SMA connector. Since we know the thickness and

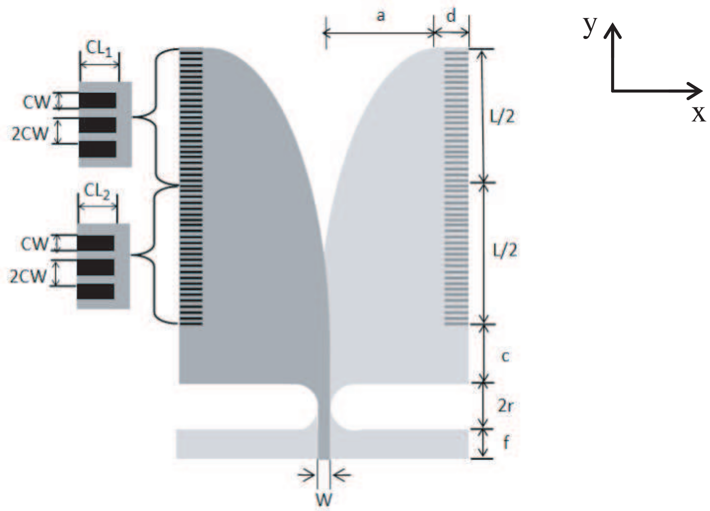

Figure 1. The structure of the antenna.

relative permittivity, we can calculate the width of the microstrip line the impedance of which is 50 Ohm. To have a good bandwidth, the translation from the microstrip line to the radiation part should be carefully designed. For the antipodal structure of the antenna, the wideband translation is possible, and we use some circular arcs. The conductor on the top of the substrate uses a quarter circular, while the one on the bottom uses both a quarter circular and a half circular. So the radii of the circular is critical to the translation effect.

The main part of the antenna is two pieces of quarter ellipse, while the major axis and minor axis is l and a, respectively. One side of the substrate is to produce one half of the conventional Vivaldi antenna, on the other side the ground plane is opposite to the top, so forming a Vivaldi antenna with two wings on different sides of the substrate.

The final goal of our work is to find a planar antenna with low return loss, high gain and good radiation patterns in the frequency range between 1 and 3 GHz. We tried massive numerical simulation to find a good compromise between these requirements, and we get a set of geometric parameters: $w = 3.4\,\text{mm}$, $a = 80\,\text{mm}$, $L = 310\,\text{mm}$, $c = 30\,\text{mm}$, $r = 4\,\text{mm}$, $f = 12\,\text{mm}$, $d = 50\,\text{mm}$, $\text{CL}_1 = 16\,\text{mm}$, $\text{CL}_2 = 15\,\text{mm}$, $\text{CW} = 1.2\,\text{mm}$.

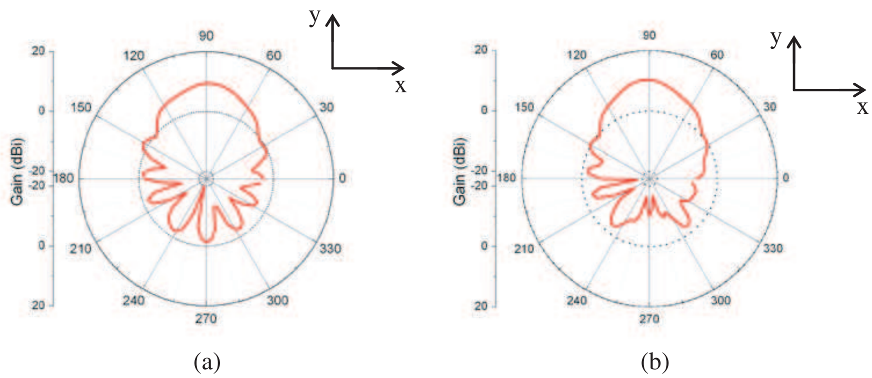

Figure 2. (a) Radiation pattern of the antenna without corrugation structure. (b) Radiation pattern of the antenna with one CL value.

2.2. Antenna with One CL Value

As we know, the corrugation structure can improve the radiation pattern. The corrugation structure consists of a periodic slits at the edges of the Vivaldi substrate. In Fig. 1, the sizes of the slits of the corrugation structure are $CW \times CL_1$ or $CW \times CL_2$, with 2CW period. CW is corrugation width, and CL is corrugation length. In Fig. 2, there are radiation patterns at 2 GHz for the antenna without corrugation structure ($CL_1 = CL_2 = 0$ mm, $CW = 0$ mm) and the antenna with one CL value ($CL_1 = CL_2 = 15$ mm, $CW = 1.2$ mm). It's obvious that the latter has narrower beam width, less backward radiation.

2.3. Antenna with Two CL Values

In this paper, we present a novel corrugated structure at the edges of the Vivaldi antenna. Compared with the traditional corrugated structure, the new structure doesn't have only one CL value but have two CL values (CL_1 and CL_2), in order to form a better radiation pattern, which we will show latter.

To make further improvements, we chose two CL values. In Fig. 1, for first half of L, the corrugation length CL_1 is 16 mm, while for the second half of L, the corrugation length CL_2 is 15 mm. In Fig. 3, there are front radiation, back radiation and F/B ratio at 2 GHz for the antenna with one CL value ($CL_1 = CL_2 = 15$ mm, $CW = 1.2$ mm) and the antenna with two CL values($CL_1 = 16$ mm, $CL_2 = 15$ mm, $CW = 1.2$ mm). We can see the F/B ratio of the new structure is almost 30 dB, while the F/B ratio of the traditional one is about 21 dB.

To avoid as much interference as possible, the improvement of the F/B ratio is very important to through-wall radar.

3. SIMULATION RESULTS

3.1. Return Loss

Figure 3 shows the simulated S11 in frequency domain. The return loss is less than -10 dB over the entire 1 to 3 GHz range, so it satisfies the proposed requirement.

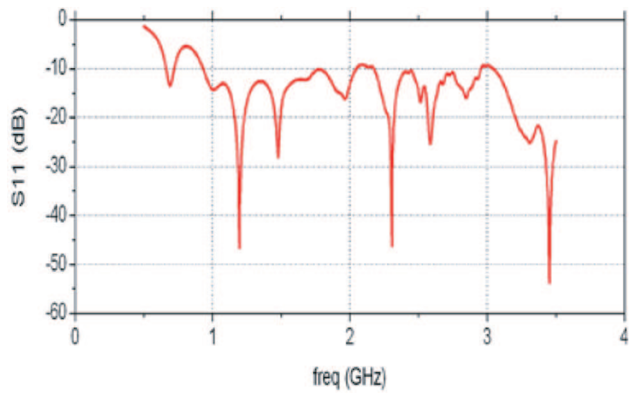

Figure 3. Return loss vs. frequency.

3.2. Boresight Gain

Figure 4 shows the simulated gain from 1 to 3.4 GHz along the boresight. The antenna gain through operating band width is with a range of 7 dBi $\sim$ 11 dBi, while most of them are around 10 dBi. The

Table 1. The F/B ratio of the antenna with one CL value and the antenna with two CL values.

	Front radiation (dBi)	Back radiation (dBi)	F/B ratio (dB)
Antenna with one CL value	10.4	-11	21.4
Antenna with two CL values	10.3	-19.6	29.9

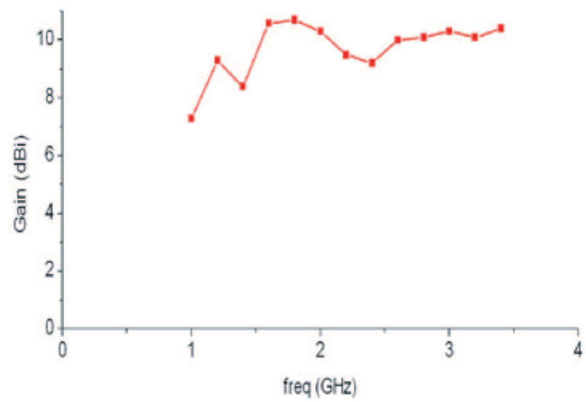

Figure 4. Boresight gain vs. frequency.

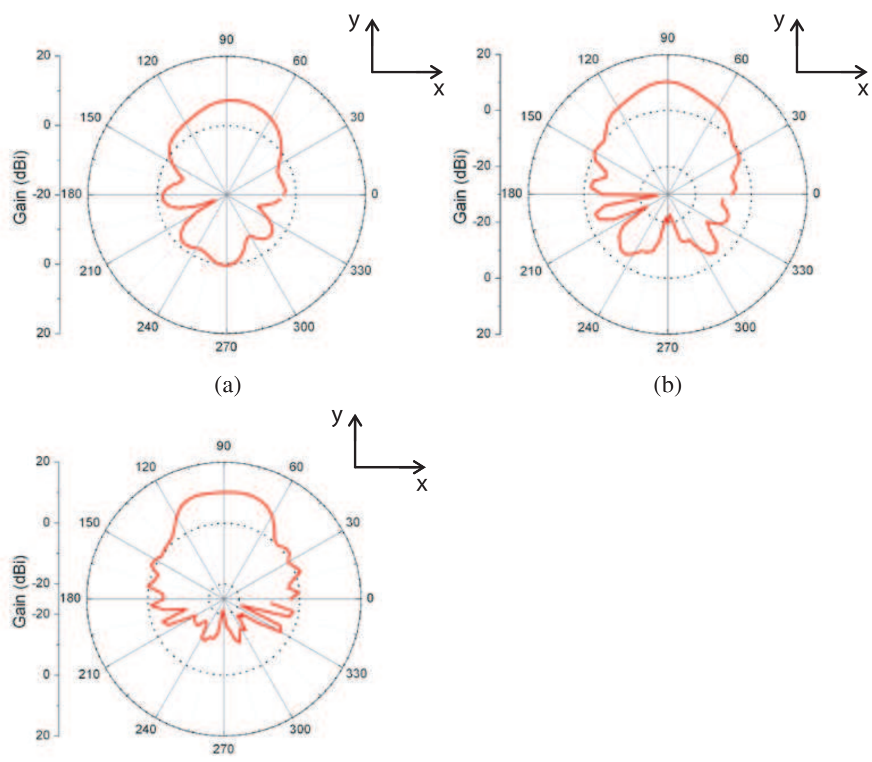

Figure 5. Radiation patterns of the new antenna at (a) 1 GHz, (b) 2 GHz, (c) 3 GHz.

gain has a good uniformity in the band between 1.6 and 3.5 GHz. For planar antennas, the boresight realized gain is high enough.

3.3. Far-Field Radiation Patterns

The far-field radiation patterns in substrate plane (E plane) of the new Vivaldi antenna are simulated at 1, 2 and 3 GHz, plotted in Fig. 5. There is a little asymmetry in the radiation patterns, and this is possibly caused by error during simulation process. We can see that main lobe directions of the three frequencies are all along the boresight (y-axis). This is important, since UWB applications need a good stability of radiation patterns and directivity over the whole operating bandwidth. The 3 dB beam width is with a range of $39^\circ \sim 61^\circ$, while the side lobe level is between -6.9 dB and -9.8 dB.

Figure 5(a) shows the E plane radiation pattern at 1 GHz. The 3 dB beam width is 61°, while the side lobe level is -6.9 dB. Fig. 5(b) shows the E plane radiation pattern at 2 GHz. The 3 dB beam width is 39°, and the side lobe level is -9.8 dB. Finally, the radiation pattern at 3 GHz is shown in Fig. 5(c). At this frequency, the 3 dB beam width is 55.8°, while the side lobe level is -9 dB.

4. CONCLUSION

A new type of high gain UWB antenna with improved corrugated edges is presented. The size of the whole antenna is $1.2\lambda_0 \times 0.86\lambda_0$, while λ_0 is the wavelength of the lower frequency. The antenna operates from 1 GHz to more than 3 GHz, while the return loss is less than -10 dB. The antenna gain through operating band width is with a range of 7 dBi $\sim$ 11 dBi, while the main lobes are always along y-axis. We also find that F/B ratio improvement is achieved by using two CL values at the edges of the Vivaldi substrate. It indicates that the performance of presented structure can meet the requirement of the through-wall radar. It is expected that this design concept can be extended to more than two CL values to achieve even better radiation patterns.

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