

A Novel Ultra-Wideband Antenna Operating in the frequency band of 2.5-40GHz

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Abstract— This paper presents a novel ultra-wideband microstrip planar antenna operating in frequency band of 2.5-40GHz. The design is based on a rectangular shaped microstrip antenna optimized by genetic algorithm. The final structure of antenna consists of a defected ground structure (DGS) and a notched radiating patch with steps. By etching a Chinese character “日” shaped slot and two symmetric wing-shaped slots on the top, and removing two kinds of irregular shape grooves from the bottom, the return loss S11 is under -10dB between 2.5-40GHz, and the relative bandwidth is 176.47%. The simulated results demonstrated that bandwidth of antenna are greatly affected by those structures.

Keywords— Genetic algorithm (GA); ultra-wideband (UWB) antenna; microstrip antenna; HFSS

I. INTRODUCTION

Following the release of the ultra-wideband (UWB) spectrum of 3.1-10.6 GHz for unlicensed use by the Federal Communications Commission (FCC) [1], UWB wireless communication developed rapidly, and many researchers have been focused on ultra-wideband (UWB) antenna design. Literature [2]-[3] introduced two kinds of three-dimensional UWB antenna, which has strong directional characteristics and is suitable for point-to-point communication. However, they are neither portable nor compact so that they aren't fit to handheld devices and civil communication system. Therefore, planar microstrip UWB antennas were proposed. Common shapes of antenna patch include circle[4], diamond[5], triangle[6], and so on. These designs achieved UWB requirements by etching slots in the radiating patch, or adding metallic strip at the end of patch, or adding regular aperture structure, or using coupling feeding. But for rectangular shaped patch, the simplest structure, their bandwidth usually is narrow because of the feature of resonance. And these UWB antenna's geometries usually are more complicated than others. The UWB antenna in [7] is composed of ELC element and EBG structure, which is not easy to fabricate. In [8], the shown antenna includes an inverted T-shaped notch in the ground plane and small rectangular radiating patch with an M-shaped cut and two rectangular slots with steps on it. They can provide plenty of bandwidth from 3 to 12.5 GHz. There is a simple Q-slot displayed in [9], which results in a reflection coefficient S11 under -10dB from 3.5 to 11.7GHz. But

considering about the rapidly increasing demands of bandwidth in 5G era, the structure mentioned just now are obviously not perfect. That's the reason why Vivaldi antenna proposed. In [10], a modified Vivaldi antenna for 4-50GHz UWB application is presented. However, the patch outline of Vivaldi antenna changes according to exponential law. This limitation brings some difficulties to design and optimize a Vivaldi antenna. Whereas a novel antenna optimized from a rectangular microstrip antenna has been demonstrated in this paper, having the impedance bandwidth of 2.5-40GHz, over 16: 1, and its relative bandwidth is 176.47%.

The proposed antenna is optimized from the simplest rectangular patch to a two-band antenna by genetic algorithm (GA). Of course there are lots of algorithms which are used to design UWB antenna. For instance, a UWB monopole antenna with hexagonal patch structure using particle swarm optimization (PSO) algorithm designed in [11]. In addition, literature [12] introduced a UWB planar monopole antenna based on multi-objective optimization techniques. These algorithms help a lot when we design an ultra-wideband antenna. Nevertheless, the solution they provide may be just locally optimal. For getting a globally optimal solution, GA is widely used in antenna design and modification. In [13], a wideband printed monopole is designed with GA, but algorithm's search space set is 2^{128} , which is so big that it has to take a long time to find a suitable solution. The search space set this paper is 2^{80} , saving a lot of time to design the basic geometry that will be optimized to the final UWB structure.

II. INTRODUCTION TO THE GENETIC ALGORITHM

As shown in Figure 1, the rectangular patch was divided evenly into a 15 by 10 grid of cells, and each cell is a square with size of 1.6mm×2mm. They can be set as “0” or “1” by genetic algorithm. Cells with 0 correspond to that the area covered by them won't be filled by metal, and cells with 1 correspond to be filled. Therefore, the whole patch is be mapped into a string of 150 bit binary code, whose search space is 2^{150} . Considering the symmetry of the patch, the grid of cells can be simplified to 8 by 10, reducing the search space to 2^{80} . The simplification greatly accelerates the convergence speed of the genetic algorithm. Besides, the ground geometry of antenna is fixed, so it won't be affected by the algorithm. A

rectangular shaped slot is introduced in ground plane for enhancing the bandwidth.

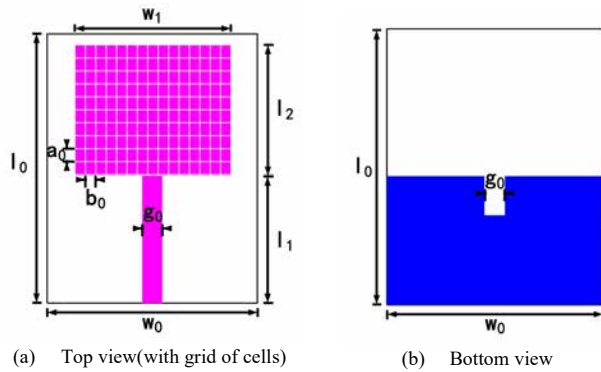


Figure 1. Geometry of primary rectangular patch antenna

III. ANTENNA DESIGN

A. Antenna Geometry

The antenna geometry after GA optimization and the simulated return loss are depicted in Figure 2. Comparing the primary rectangular patch structure without GA iteration and the final structure of patch through 30th iteration, GA obviously brought a great enhancement on antenna design.

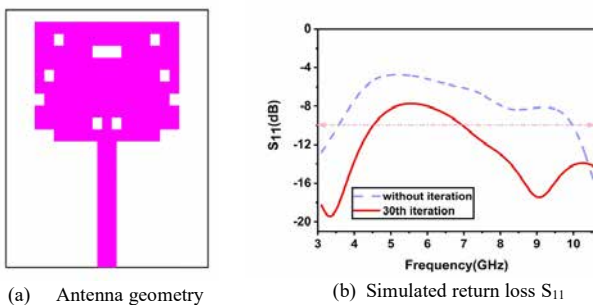
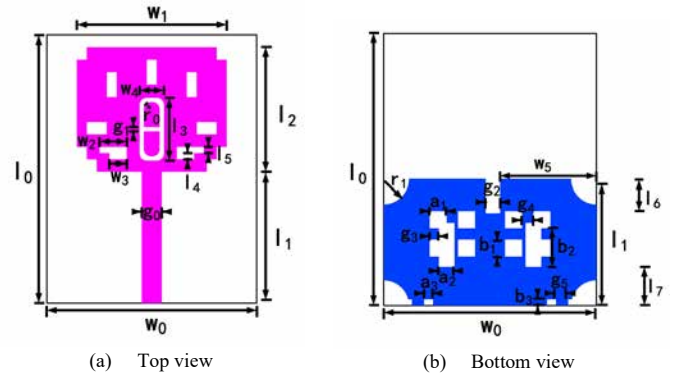


Figure 2. Antenna geometry optimized and its simulated return loss

After 30 times iteration, the antenna geometry can operate between 3.1-4.2GHz and 6.1-10.6GHz, which nearly met requirements of UWB antenna bandwidth. To expand the bandwidth further, the antenna structure needed modification.

There still is challenging to design a really UWB microstrip patch antenna, although it is pretty common to see a microstrip patch antenna in mobile and personal communications. A lot of ways to achieve the UWB antenna have been reported in literatures [14]-[16], such as slots on patch, ground with defected structure, metamaterial and so on. However, these complicated geometry antenna proposed are just operated in around 3.1-10.6GHz. They could implement a wider bandwidth. The final structure of antenna is displayed in Figure 3. Compared with GA optimized structure, there are some elements increased in the final version. A slot whose shape is similar to Chinese character “日” and two symmetric wing-shaped slots are cut from metal patch. Every corner of ground added a circle defect, and two kinds of irregular shape subtracted from ground. What's more, the width of the rectangular shaped slot became narrower, which

breaks the symmetry of the ground. In Figure 4, compared the return loss of the antenna geometry after 30 times iteration with the final version geometry, it is easy to know that these elements deeply enhanced the performance of antenna. The parameters for the antenna final design, which results in a reflection coefficient S_{11} under -10dB from 2.5 to 40 GHz, are summarized in Table 1. By the way, the material of substrate is FR4-epoxy, and the substrate thickness is 1.6mm.



antenna performance, this study examined the effect of the following parameters with reference to Figure 5 (a)-(c): circle radius r_1 , the width g_2 of rectangular shaped slot in ground, and the width w_4 of slot whose shape is similar to “日”. Furthermore, when reducing one of those elements added in final antenna structure, the changes were also shown in Figure 5 (d).

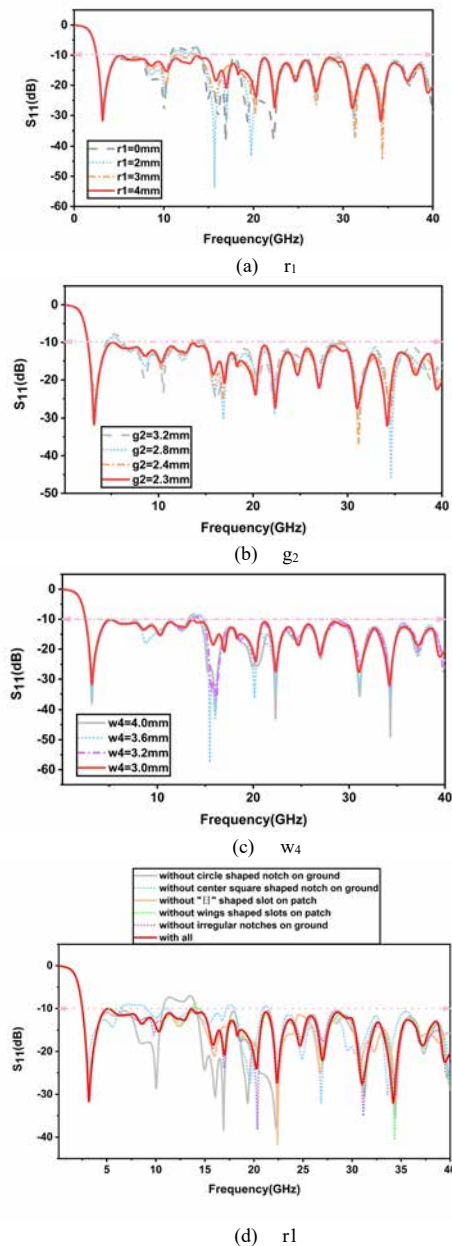


Figure 5. (a-c) Simulated return loss S_{11} when varying one parameters at a time and keeping all others fixed in Table I. (d) Simulated return loss S_{11} when changing the structure of antenna ground and patch.

Figure 5 plots the antenna's return loss S_{11} as a function of each of the three parameters and of each element reduced. For all three parameters and elements under study, our final choices resulted in broadest bandwidth for S_{11} under -10dB (solid red line). It is clear from these plots that all parameters elements have impact on the antenna reflection coefficient

more or less.

Changing the circle radius r_1 affects both strength and location of the resonant frequencies as well as the frequency range where $S_{11} < -10$ dB, with $r_1=4$ mm producing the widest bandwidth [see Figure 5 (a)]. Relative to the finalized design, changes in the parameters r_1 , g_2 , w_4 and increase of those elements can improve matching (i.e., lower the S_{11}) in some particular range of frequency, such as 14-20GHz and 8-11GHz, but result in a narrower bandwidth for whose $S_{11} < -10$ dB. As indicated in Figure 5 by comparing the various lines to the solid red line of the final design, in terms of directivity, it will be affected by changing parameters about circle shaped notch, center square shaped notch and “日” shaped slot. For all other cases, the radiation pattern does not vary much from the values of the final design.

IV. CURRENT DISTRIBUTION AND RADIATION CHARACTERISTICS

Surface current distributions and contours were studied. After modeling the antenna in HFSS, current distributions at respective frequencies of 3.5GHz, 6.5GHz, 10GHz, 15GHz, 21GHz, 30GHz, shown in Figure 6. As the operated frequency increases, the current concentrated along the edge of both top and bottom layer becomes weaker and weaker, and almost disappears in 30GHz. Meanwhile, the surroundings of the “日” slot distributed by more and more surface current. And multiple maxima can be observed in feed line, and was changing faster with the increasing of frequency.

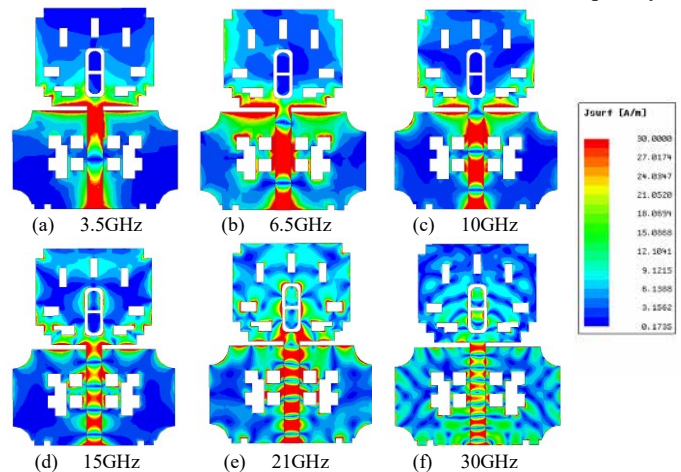
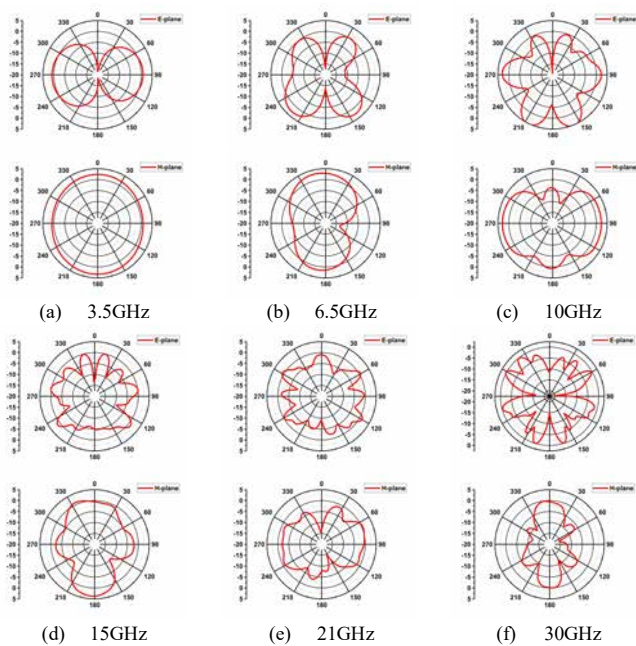


Figure 6. Calculated surface current distributions at respective frequencies of 3.5GHz, 6.5GHz, 10GHz, 15GHz, 21GHz, 30GHz

The radiation patterns of the antenna in the E and H planes were evaluated at six representative frequencies of 3.5GHz, 6.5GHz, 10GHz, 15GHz, 21GHz, 30GHz. Figure 7 shows the simulated radiation patterns at aforementioned frequency points. In the E plane, the antenna is more directive at lower frequencies, which means, at higher frequencies, it tend to scatter more energy and to become quasi-omnidirectional. In H plane, the radiation patterns are getting less omnidirectional with increasing frequency.



V. CONCLUSIONS

This paper presents a novel microstrip ultra-band antenna which is optimized by GA and modified with defected ground structure and special shaped slots on antenna patch. Finally it yields an impedance bandwidth of 2.5-40 GHz with $S_{11} < -10$ dB. Through the study of effects of particular parameters and elements, the widest bandwidth was achieved. And the slot shape similar to Chinese character “日” makes the proposed antenna distinctive from all the other UWB antennas. Performances of surface current and radiation pattern with the change of frequency also discussed in this paper. The higher frequency, the more complex the performances are. The presented antenna is characterized of compact geometry and super wide bandwidth, optimized for wireless applications from Wi-Fi band up to K_a band, suitable for UWB application with high demands in bandwidth.

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