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Bandwidth Enhancement of a Printed Slot Antenna with a Diamond-Shaped Tuning Stub

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Abstract—A printed slot antenna fed by a microstrip line with a diamond-shaped tuning stub for bandwidth enhancement is proposed and experimentally validated. Impedance bandwidth, radiation pattern, and gain characteristics of the proposed antenna are investigated. The simulated results show that the impedance matching of the proposed rotated slot antenna is greatly affected by the dimension of the slot and by the size and the position of the diamond-shaped tuning stub. The experimental results demonstrate that this antenna exhibits an ultra-wide impedance bandwidth, which is over 123% for $|S_{11}| \leq -10\,\mathrm{dB}$ ranging from 2.80 to 11.81 GHz. Moreover, a stable and omnidirectional radiation pattern is observed within the operating bandwidth.

1. INTRODUCTION

With the rapid development of wireless communication systems and increase of their applications, compact and broadband antenna design has become a challenging topic. Frequently used wideband antennas include modified dipole antennas, Vivaldi antennas, water-drop antennas, printed slot antennas and so on. Vivaldi antenna has advantages such as wide bandwidth, high directivity, low profile and ease of fabrication, however its size is relatively large [1]. Water-drop antennas have a better impedance matching but without a compact structure. Meanwhile, microstrip-line-fed printed slot antenna has attracted much attention due to its simple structure, favorable impedance bandwidth, small size, completely uniplanar and easily integrated with active devices or circuits [2, 3]. Nakano and Yamauchi summarized printed slot and wire antennas in a review, and mentioned that one of approaches to achieve wideband characteristics is to combine a wide slot with a tuning stub [4].

In recent decade, a series of printed wide-slot antenna have been investigated. Sze and Wong presented a printed wide-slot antenna with enhanced bandwidth via increasing the coupling between the microstrip feed line and the printed wide slot by the fork-like tuning stub [5]. Liu and coauthors suggested in the study of printed wide-slot antenna for wide-band applications that the antenna feed and slot should be of similar shapes for optimum impedance matching [6]. This idea has been adopted in design of various slot antennas with different shape for bandwidth enhancement [7–10].

Jan and Su demonstrated that a wide operating bandwidth can be obtained by rotating the square slot because another resonant mode can be excited, and they suggested that 45 degree rotation is a good choice [11]. Based on such a design, Chen and coauthors also obtained the bandwidth enhancement by etching the wide-slot as fractal shapes [12]. Later, Sung extended the antenna design by embedding a parasitic patch into the center of the rotated square slot to decrease the lower resonant frequency and increase the higher one, which improves the bandwidth to 82.8% (2.23–5.35 GHz) [13]. Fan and coauthors added a pair of parasitic patches along the microstrip feed line and the impedance bandwidth has been improved from 82.8% to 136% [14].

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Based on these studies, a printed wide-slot antenna with a parasitic center square patch fed by a diamond-shaped tuning stub is proposed in this paper to increase the impedance bandwidth. This paper uses the structure proposed in [13] as a reference antenna. Different from the design in [13, 14], the slot is fed by a diamond-shaped tuning stub instead of a microstrip line with or without parasitic patches to make the proposed antenna more compact while keep a wider bandwidth at the same time. By choosing suitable parameters, a significantly enhanced wideband impedance bandwidth and good radiation characteristics are obtained. Both the simulated and experimental results show that the obtained -10 dB impedance bandwidth is improved from 82.8% to 123% (2.80 to 11.81 GHz), compared to the reference antenna in [13] and comparable to 136% for the design in [14], while the total area of the proposed antenna is only $28 \times 28\,\mathrm{mm}^2$, much smaller than $37 \times 37\,\mathrm{mm}^2$ for the antenna in [14].

This paper is organized as follows to effectively present the antenna design. The proposed antenna geometry is described in Section 2. Several key parameters which influence the optimization and bandwidth are discussed in Section 3. Some experimental results and discussion are shown in Section 4, and we summarize our conclusion in Section 5.

2. ANTENNA CONFIGURATION

The configuration of the proposed antenna is shown in Figure 1. The antenna is composed of a wide-slot, a parasitic patch and a diamond-shaped tuning stub connected with a 50-Ω microstrip line. Both the printed wide slot and the parasitic patch are chosen to be squares with edge length of S_1 and S_2 respectively, and rotated 45 degree. They are printed on a substrate with a thickness of 1 mm and a relative permittivity of 2.65. The ground plane is also chosen to be a square with a side length G of 28 mm. The white regions in Figure 1 represent the etched slot and the light gray region surrounded by the dashed lines denotes the feed line on the opposite side of the ground plane.

The lower resonant frequency decreases with an increase in the length S_1, due to lengthened effective current path [13]. A parasitic patch with side length of S_2 is embedded into the center of the rotated square slot to excite additional resonance by creating another surface current path, and therefore a much wider impedance bandwidth can be obtained. In order to excite more resonances to broaden the bandwidth even further, a tuning stub rather than a simple 50-Ω microstrip line is chosen as the feed of the antenna. The tuning stub is designed as diamond shape according to the suggestion that the antenna feed and slot should be of similar shapes [6]. It is connected to a 50-Ω microstrip feed line with width of $w_f = 2.66$ mm. L denotes the side length of the diamond-shaped stub, and L_{off} denotes the distance between the parasitic patch center and the diamond center. All the simulations are implemented using CST Microwave Studio, a commercial electromagnetic simulator based on time domain numerical method.

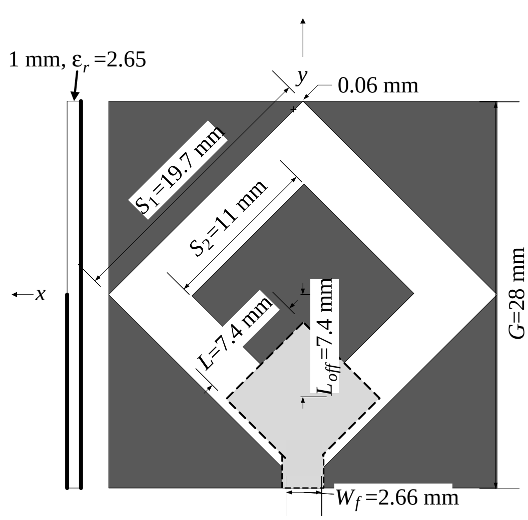

Figure 1. Geometry of the proposed slot antenna.

3. PARAMETER DISCUSSION

In this section, a discussion is presented to understand the effects of various parameters and to optimize the performance of the final design. Moreover, the parameters of this proposed antenna are investigated by changing one parameter at a time and fixing the others. After a thorough parametric study, the optimum design dimensions for the proposed antenna are set as follows: $G = 28\,\text{mm}$, $S_1 = 19.7\,\text{mm}$, $S_2 = 11\,\text{mm}$, $w_f = 2.66\,\text{mm}$, $L_{off} = 7.4\,\text{mm}$, and $L = 7.4\,\text{mm}$

Figure 2 and Figure 3 show the simulated reflection coefficient of the proposed antenna in terms of the length S_1 and G. As shown in Figure 2, the length S_1 of the rotated square slot is mainly to determine the first three resonances at about 3 GHz (f_1), 4.3 GHz (f_2) and 6.5 GHz (f_3). When S_1 increases from 18 mm to 19 mm, the lower resonant frequencies are shifted downward, resulting in the lower edge of the operating frequency band also moved downward. The reason for this is the increase of S_1 lengthens the effective current path. As S_1 further increases to 19.7 mm, the impedance match becomes better at the lower frequencies. The impedance match is sensitive to S_1 because the small change of S_1 leads to a big variation of the current path around left and right corners of the slot when the ground is fixed to 28 mm. Moreover, a huge fluctuation happens if $S_1 \geq 20\,\text{mm}$ since the ground

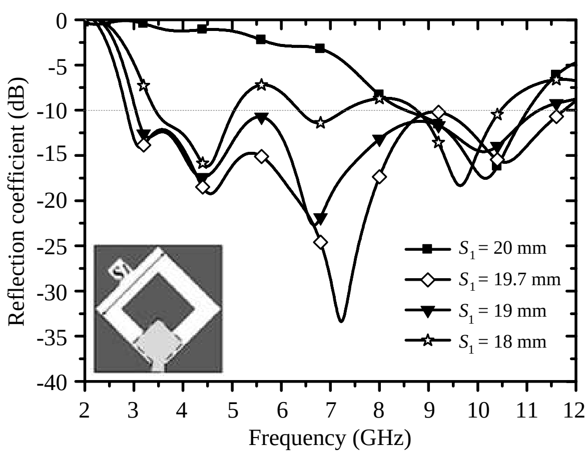

Figure 2. Simulated reflection coefficient of the proposed antenna in terms of length S_1.

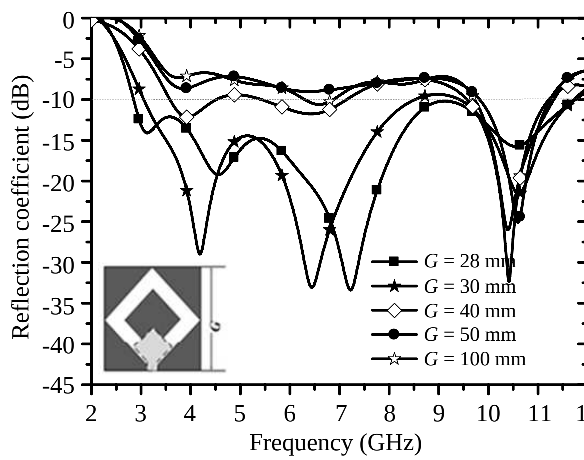

Figure 3. Simulated reflection coefficient of the proposed antenna in terms of length G.

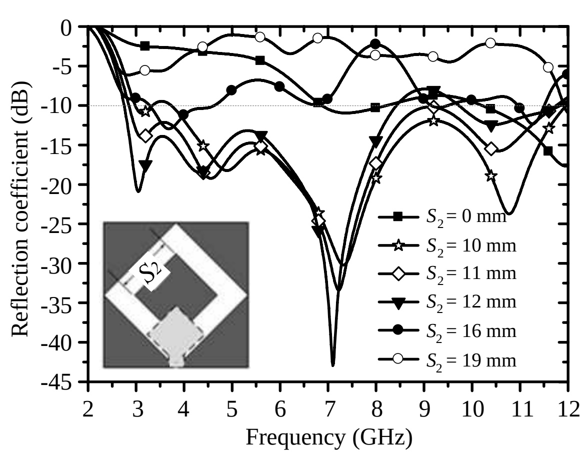

Figure 4. Simulated reflection coefficient of the proposed antenna in terms of length S_2.

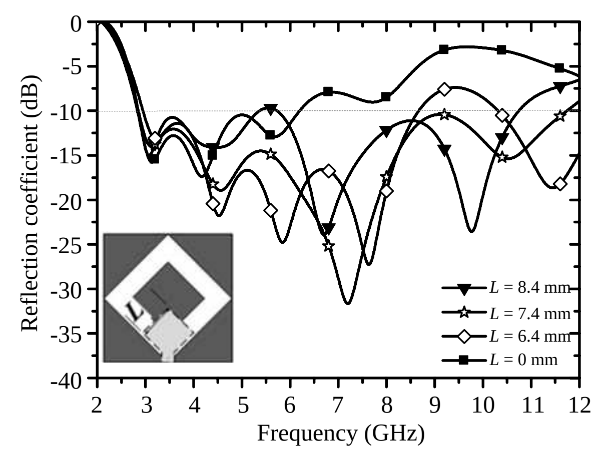

Figure 5. Simulated reflection coefficient of the proposed antenna with different lengths L. (Note that $L = 0\,\text{mm}$ means the microstrip line without the tuning stub).

is cut into four parts, which causes the wide-slot antenna turning into a monopole antenna with five parasitic patches. Consequently, current flowing path varies correspondingly. The length of the ground G also plays an important role for lower resonances, as shown in Figure 3. The resonances f_2 and f_3 moves downward as G increases from 28 mm to 30 mm, but disappear when G increases to 40 mm and further. The reason for that is part of current flows along the left and right edges of the ground when G is small, and mainly concentrates around the slot after G becomes larger than 40 mm. So even if G increases to 100 mm, there is almost no change in Figure 3.

The simulated results shown in Figure 4 demonstrate that the parasitic patch also play an important role on widening the bandwidth of the slot antenna. As stated in [13], the parasitic center patch is used as both the radiator and feed structure for the antenna. With the change of length S_2, the coupling between the center patch and the feed line or between the patch and the ground also vary. When the length of S_2 further increases and approaches S_1, the slot becomes very thin and the impedance of the proposed antenna cannot be matched at all.

Another vital influence on the impedance bandwidth enhancement is caused by the coupling effects between the slot and the feed structure. The effects of the length L and L_{off} on the proposed antenna are discussed and results are shown in Figure 5 and Figure 6.

As shown in the Figure 5, a resonance at higher frequency is excited by adding a diamond-shaped tuning stub, resulting in a very wide frequency band. Once changing the length L or L_{off}, the overlapping

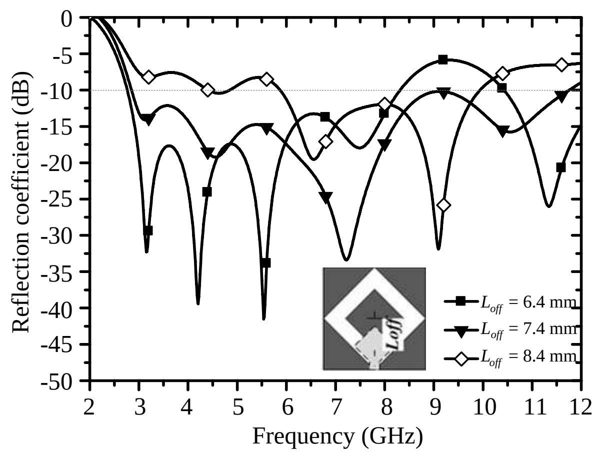

Figure 6. Simulated reflection coefficient of the proposed antenna on terms of length L_{off}.

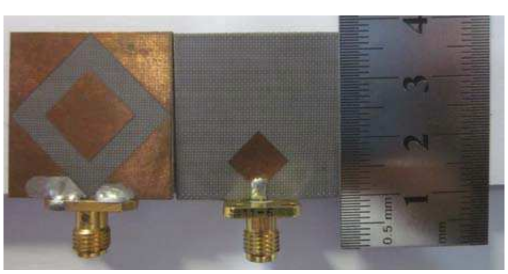

Figure 7. Picture of the fabricated antenna.

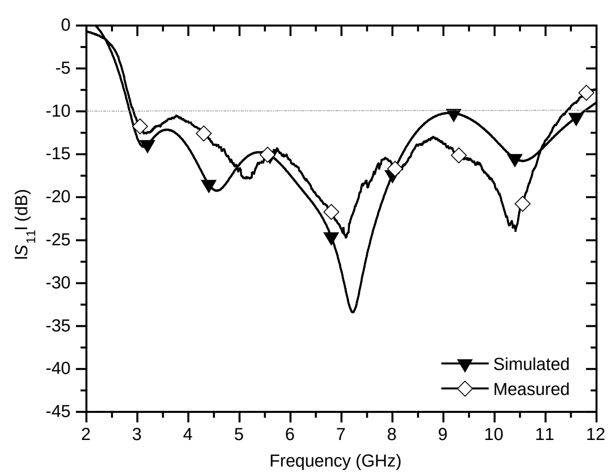

Figure 8. Simulated and measured reflection coefficient of the proposed antenna.

area between the tuning stub and the center parasitic patch, as well as the gap between the tuning stub and the ground are changed at the same time. Consequently the coupling capacitance and the inductance are changed and affect the impedance bandwidth.

4. MEASURED RESULTS

In order to validate the simulation results, the proposed antenna was fabricated, and measured. The picture of the prototype is shown in Figure 7. The return loss of the fabricated antenna was measured using Agilent Vector Network Analyzer N5225A, and the results in comparison with the simulated ones

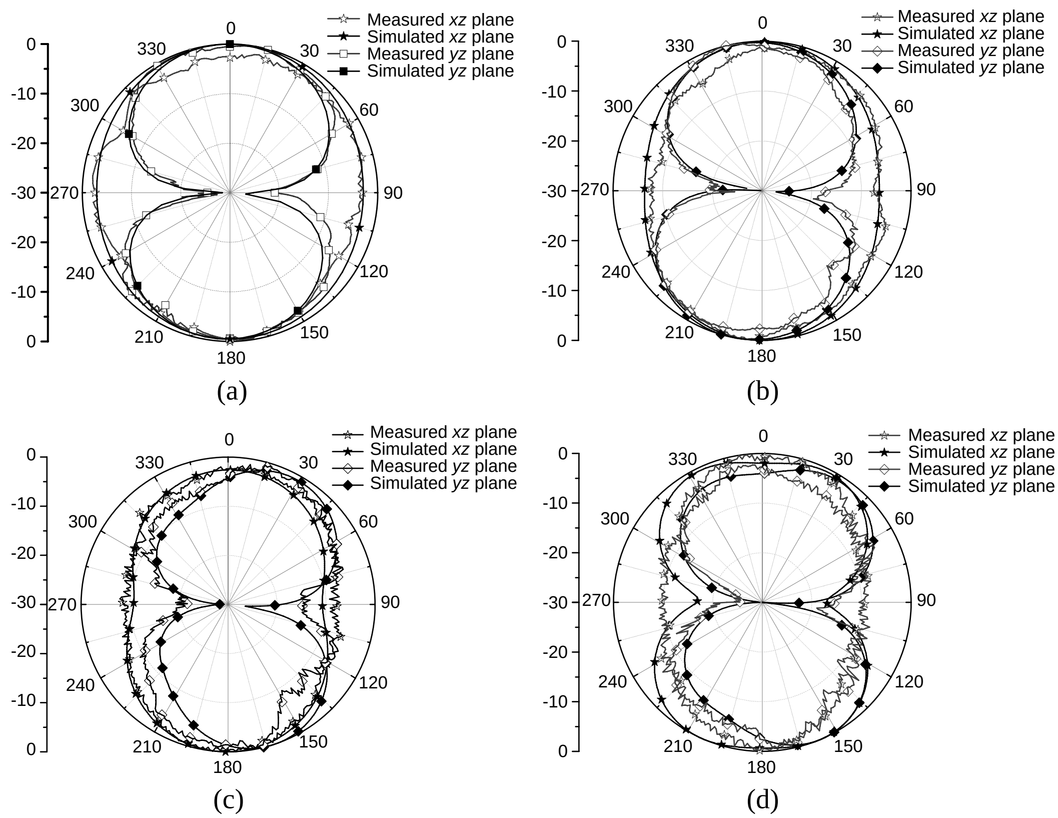

Figure 9. Simulated and measured radiation pattern at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz, (d) 9 GHz.

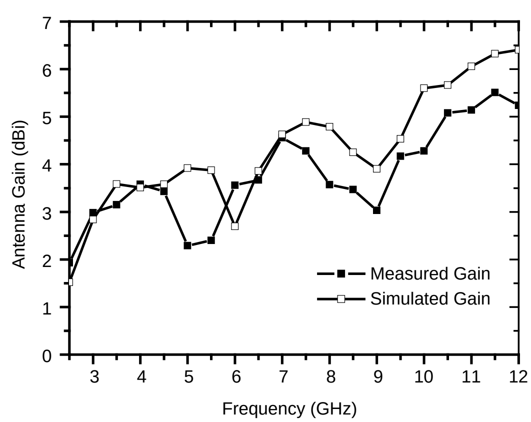

Figure 10. Simulated and measured peak gain of the proposed antenna.

are shown in Figure 8. It can be seen from Figure 8 the proposed antenna has a good bandwidth of 123%, ranging from 2.80 to 11.81 GHz for $|S_{11}| < -10\,\mathrm{dB}$, and the measured results agree with the simulated ones.

Figure 9 shows the simulated and measured E-plane (xz-plane) and H-plane (yz-plane) radiation pattern of the proposed antenna at 3 GHz, 5 GHz, 7 GHz, and 9 GHz. We can see that the measured results are in good agreement with the simulated ones. It is clear that the antenna radiation patterns are nearly omni-directional at xz-plane and directional at yz-plane. The radiation pattern gets distorted as the operating frequency increases. That is mainly due to the excitation of the higher-order mode.

Figure 10 shows the simulated and measured gain of the antenna. Measured results are in good agreement with simulated ones at the lower frequency. The discrepancy between those measured and simulated results may be from fabrication imperfections and SMA adaptor welding effects.

5. CONCLUSION

In this paper, a printed rotated square slot antenna with a diamond-shaped tuning stub for impedance bandwidth enhancement has been demonstrated. The optimum parameters are determined by varying the main dimension parameters of the antenna respectively. Note that the size of both the ground and the slot influences the performance of the proposed antenna greatly, and the impedance is sensitive to the length S_1 and G. These parameters should be chosen carefully in applications. Simulated and measured results show that the impedance bandwidth of a printed wide slot antenna with a parasitic center patch can significantly be improved by adding a tuning stub. The proposed antenna can operate from 2.80 to 11.81 GHz with $|S_{11}| < -10\,\mathrm{dB}$, and display a good omnidirectional radiation pattern and relative high gain. Moreover, the antenna has a size reduction about 43% as compared to the reference antennas.

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