Bandwidth Enhancement of a Microstrip Line-Fed Printed Wide-Slot Antenna With a Parasitic Center Patch

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***Abstract*—A printed wide-slot antenna with a parasitic patch for bandwidth enhancement is proposed and experimentally investigated. A simple 50-Ω microstrip line is used to excite the slot. A rotated square slot resonator is considered as reference geometry. The rotated square slot antenna exhibits two resonances (f_1: lower resonant frequency, f_2: higher resonant frequency). By embedding a parasitic patch into the center of the rotated square slot, the lower resonant frequency f_1 is decreased and the higher resonant frequency f_2 is increased. Thus, broadband characteristic of the wide-slot antenna is achieved. The measured results demonstrate that this structure exhibits a wide impedance bandwidth, which is over 80% for $|S_{11}| \leq -10$ dB ranging from 2.23 to 5.35 GHz. Also, a stable and omnidirectional radiation pattern is observed within the operating bandwidth. In this design, a smaller ground plane is considered compared to the reference antenna (rotated square slot antenna without the parasitic center patch).**

***Index Terms*—Wide-slot antenna, wideband antenna.**

I. Introduction

With the rapid development of wireless communication systems and increase in their applications, compact and wideband antenna design has become a challenging topic [1]. Printed slot antennas are widely used in a variety of communication systems because wide-slot antennas have two orthogonal resonance modes, which are merged to create a wide impedance bandwidth [2]. Thus, printed slot antennas have recently received a great deal of attention from researchers.

As is well known, antennas with various shapes such as circle [3], ellipse [4], and triangle [5] were reported for wide bandwidth. Each slot shape requires a feed stub of appropriate shape. An optimum impedance bandwidth can be obtained by the coupling between the feeding structure and the slot [6]–[9]. In [6], a printed wide-slot antenna fed by a microstrip line with a fork-like tuning stub provided broad bandwidth through the proper parameters of the fork-like tuning stub. It was shown in [7] that introducing an L-shaped slot with a W-shaped feed stub can improve bandwidth. In [10] and [11], the authors proposed a novel bandwidth enhancement technique for a microstrip-fed wide-slot antenna based on fractal shapes. By etching a wide slot as fractal shapes, significant bandwidths enhancement of the proposed wide-slot antenna was achieved. However, it makes the configuration of the wide-slot antenna more complicated.

The square slot antenna has a relatively wider bandwidth than other types of antennas, but its applicability as a broadband antenna is limited due to the characteristics of a single resonant mode. In [12], by rotating the square slot, the other resonant mode operating near one of a conventional wide-slot antenna can be obtained. As a result, a wide operating bandwidth of about 2200 MHz (49.4%) with respect to the center frequency at 4453 MHz was obtained. However, it is not enough for the operating bandwidth to cover more wireless communication services.

In this paper, we present a compact microstrip line-fed printed wide-slot antenna with a parasitic center patch for bandwidth enhancement, and radiation characteristics of such a design are also investigated. This paper uses the structure proposed in [12] as a reference antenna. From the simulated and measured results, it is shown that f_1 (lower resonant frequency of the reference antenna) is decreased and f_2 (higher resonant frequency of the reference antenna) is increased by embedding the parasitic patch in the slot center. This improves the bandwidth of the reference antenna by more than 1 GHz. A detailed simulation is conducted to understand its behavior and optimize for broadband operation in Section III. From the measured results, the obtained impedance bandwidth (determined from 10-dB reflection coefficient) of the proposed antenna can operate from 2.225 to 5.355 GHz covering the 2.4/5.2/5.8-GHz WLAN bands and 2.5/3.5/5.5-GHz WiMAX bands. In this case, the total area (including ground plane) of the proposed antenna total area is 37×37 mm^2. It has a size reduction of about 72%, as compared to the designed antenna in [12]. Also, stable radiation pattern and low cross polarization in the entire operating bandwidth can be achieved.

II. Antenna Configuration

The geometry of the proposed microstrip-fed wide-slot antenna is illustrated in Fig. 1. The proposed antenna has a simple configuration, consisting of a rotated square slot and a parasitic patch. The rotated square slot has a side length of s_1. The length s_1 of the slot determines the lower resonant frequency. With an increase in the length s_1, the lower resonant frequency is shifted downward. Thus, the lower edge of the operating frequency band of the proposed antenna also moves downward. This is because the increase in length s_1 will lengthen the effective current path. In general, it is desirable to select a stub that is parallel to the slot edges. Therefore, the center patch is

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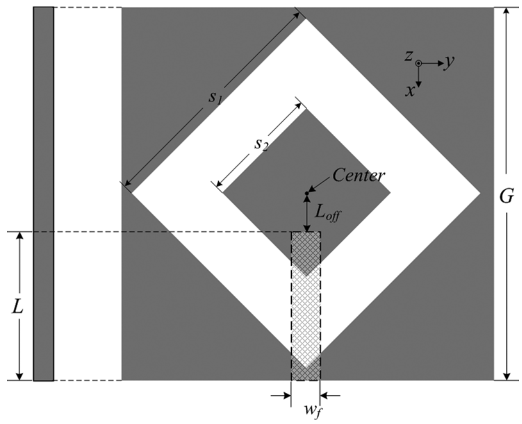

Fig. 1. Geometry of the proposed wide-slot antenna.

inclined with respect to the y-axis at an angle of 45° shown in Fig. 1. Its side length is denoted by s_2. The parasitic center patch acts as the radiator as well as the feed structure for the rotated square slot antenna. In this paper, the parasitic patch plays an integral role of widening the bandwidth of the slot antenna while minimizing the overall size of the antenna including the ground plane.

The antenna is fabricated on commercially available FR4 dielectric substrate with a permittivity of 4.4 and a thickness of 1.6 mm. The rotated square slot is printed on one side of the substrate. White and gray regions represent etched slot on the ground plane and bottom metal, respectively. In order to obtain a stable symmetrical radiation pattern, the parasitic patch is embedded into the center of the slot. The dotted line represents the feed line on the opposite side. To simplify the design, the width $w_{\rm f}$ of the feed line is chosen to be 3 mm, which corresponds the characteristic impedance of 50 Ω. The length of the feed line is set as L. In here, the length $L_{\rm off}$ is the distance between the slot center and the edge of the feed line. Based on the simulated results, the length $L_{\rm off}$ of the feed structure can be adjusted for good impedance matching. The ground plane size is denoted by G. Compared to the designed antenna in [12], the proposed antenna has better bandwidth and much smaller size. Simulation is carried out using HFSS, a commercial electromagnetic simulator based on a finite element method (FEM).

III. Parameter Study

In this section, a parameter study is carried out to understand the effects of various parameters and to optimize the performance of the final design. Fig. 2(a) shows the simulated reflection coefficient for the reference antenna with different ground plane sizes. As proposed in [12], the same FR4 substrates are used, and the antenna parameters are set identically. The dimensions of the proposed antenna are as follows: $s_1 = 24.7$ mm and $w_f = 3$ mm. However, the length of the feed line, L, cannot remain constant as it changes by the size of the ground plane. According to [12], the rotated square-slot antenna, where $G = 70$ mm, has an optimized bandwidth when $L = 31.5$ mm. All these values suggest that $L_{\rm off}$ is 3.5 mm, and therefore this paper maintains $L_{\rm off}$, instead of the variable L, at a constant value of 3.5 mm

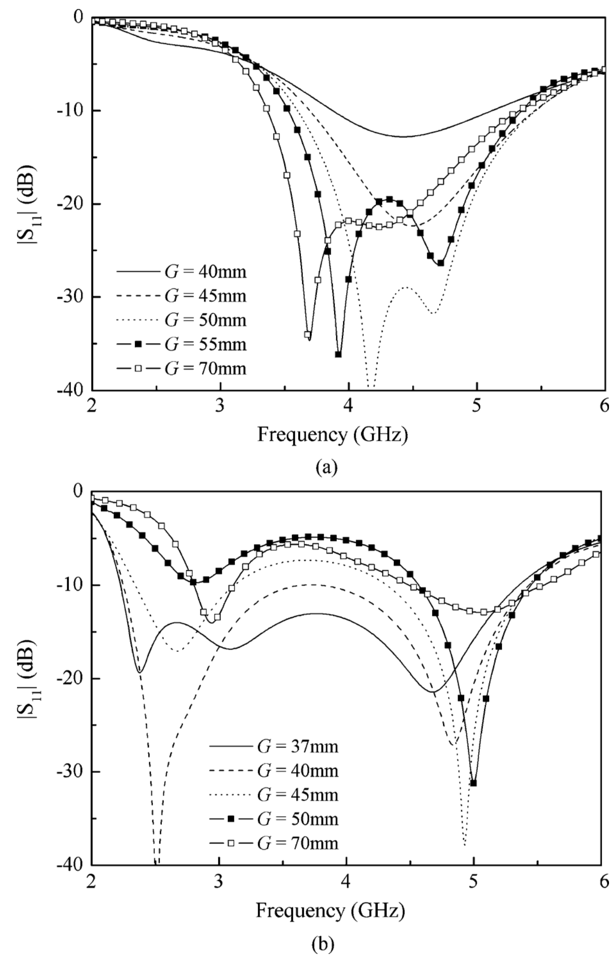

Fig. 2. Simulated reflection coefficient of the two antennas with different ground plane sizes. (a) Reference antenna. (b) Proposed antenna.

From the simulated result, it is shown that the bandwidth of the reference antenna has effect on the ground plane size. The bandwidth of the proposed antenna increases from 27.8% to 45.7% as the ground plane size G increases from 40 to 70 mm. The bandwidth, however, does not increase any further when the size of the ground exceeds 70 mm. When $G = 70$ mm, the bandwidth of the slot antenna obtained through a simulation stands at 45.7%, which is very close to the measured value of the bandwidth (48.9%) suggested in [12].

Fig. 2(b) shows the simulated reflection coefficient for the proposed antenna with different ground plane sizes. In order to compare the bandwidth characteristics of the reference and proposed antennas more accurately, all the parameters are set as described above. The side length (s_2) of the parasitic center patch is assigned to be 12 mm. As illustrated in Fig. 2(b), the parasitic patch leads the proposed antenna to have a lower resonant mode than f_1 of the reference antenna and a higher resonant mode than f_2. In this case, the variation of f_1 is considerably greater than that of f_2. As for the wideband antenna that has two resonant modes (i.e., f_1 and f_2), its bandwidth becomes wider as the distance separating f_1 and f_2 increases, which generally worsens the matching characteristics between the two frequencies. For instance, the resonant frequencies of the reference antenna described in Fig. 2, where $G = 70$ mm, stand at 3.7 and 4.3 GHz, respectively. Meanwhile, the two frequencies of the proposed antenna, whose ground is sized the same, are 2.9 and 5.0 GHz, with their separation distance further widening. As $|S_{11}|$ at a 3.7 GHz increases up to -6.5 dB, it does not demonstrate any broadband characteristics.

The proposed antenna shows better antenna matching characteristics across the entire operating bandwidth as the ground plane declines in size. As Fig. 2(b) illustrates, $|S_{11}| \geq -10$ dB at 3.7 GHz when the size of the ground plane exceeds 45 mm (i.e., $G = 45$ mm), and therefore the proposed antenna proves unfit to be used as broadband antenna. Meanwhile, the overall matching characteristics improve when $G = 40$ mm or below, with the matching characteristics at 3.7 GHz falling below -10 dB, and thus the antenna demonstrates broadband characteristics. The simulated results indicate that as the size of the ground plane decreases, the upper edge of the proposed antenna's operating bandwidth remains nearly unchanged at around 5.3 GHz while its lower edge becomes smaller. This increases the bandwidth of the antenna, as its matching characteristics at 3.7 GHz are enhanced and its lower edge declines. Also, the two resonant frequencies f_1 and f_2 are lowered in accordance with decrease of the ground plane size.

Generally, the bandwidth of the wideband antenna decreases as the ground plane size decreases. Therefore, the overall size of the antenna, including the ground, will likely be fairly large in order to have broadband characteristics; this serves as an obstacle in making compact antennas with broadband characteristics. The proposed structure may be used as a compact-sized broadband antenna, as its bandwidth increases even though the size of the ground is smaller. In the simulated results, the bandwidth of the proposed antenna when $G = 40$ mm is 84%, ranging from 2.25 to 5.44 GHz. However, it is reasonable to infer from Fig. 2(b) that the antenna performances are influenced by the mounting support as well as the antenna surroundings. Thus, there may be some limitation for the proposed design.

An important feature of the proposed antenna is the influence of impedance matching caused from the coupling effects between the slot and the feed structure. For this reason, the effects of the length $L_{\rm off} = 2.5, 3.5, 4.5$, and 5.5 mm on the performance of the proposed antenna are also studied and presented in Fig. 3. The side length (s_1) of the slot is 24.7 mm. The side length (s_2) of the parasitic patch is 12 mm. The ground plane size G is 40 mm. Large change at the lower resonant frequency due to the variation in $L_{\rm off}$ is observed. This is because decreasing the $L_{\rm off}$ significantly increases the total capacitive effect and thus lowers the lower resonant frequency. The impedance bandwidth changes significantly with varying the parameter $L_{\rm off}$. This is due to the sensitivity of the impedance matching to the parameter $L_{\rm off}$. However, the effects on the upper resonant mode contributed by the length $L_{\rm off}$ of the feed line are smaller. As the length $L_{\rm off}$ increases, the upper resonant mode shows a worse matching with the corresponding resonant frequency remaining unchanged. With the length $L_{\rm off}$ chosen to be 3.5 mm, the impedance bandwidth has the optimum value in this study.

Fig. 4 demonstrates the simulated reflection coefficient of the proposed antenna for various s_2. The other parameter values used are the following: $s_1 = 24.7$ mm, $L_{\rm off} = 3.5$ mm, and $G =$ 40 mm. It is from the simulated results shown that the two resonant frequencies f_1 and f_2 are decreased as the side length s_2 increases. f_1 declines as s_2 becomes longer because capacitance increases as the overlapping area between the center patch and the feed line widens. f_2 becomes smaller because the coupling between the patch and the ground improves as the center patch

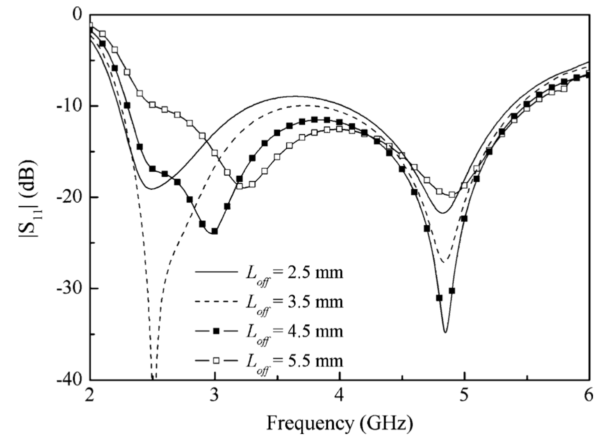

Fig. 3. Simulated reflection coefficient of the proposed antenna with different offsets $L_{\rm off}$.

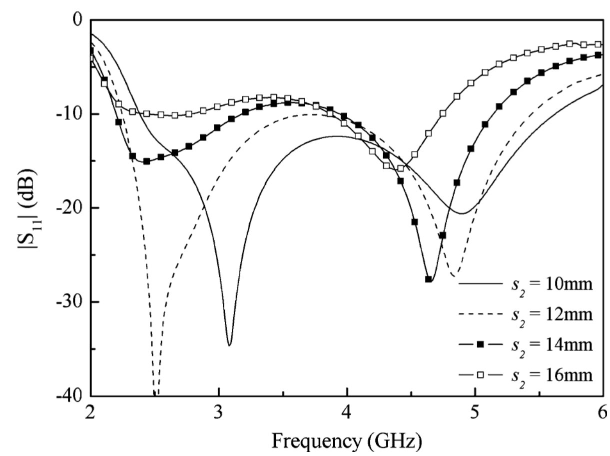

Fig. 4. Simulated reflection coefficient of the proposed antenna with different lengths s_2.

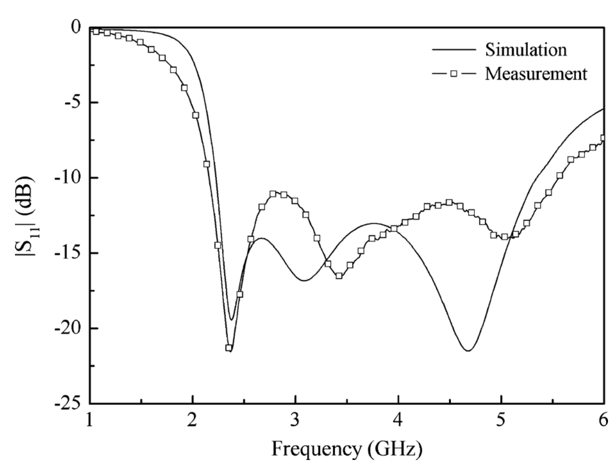

Fig. 5. Simulated and measured reflection coefficient of the proposed antenna.

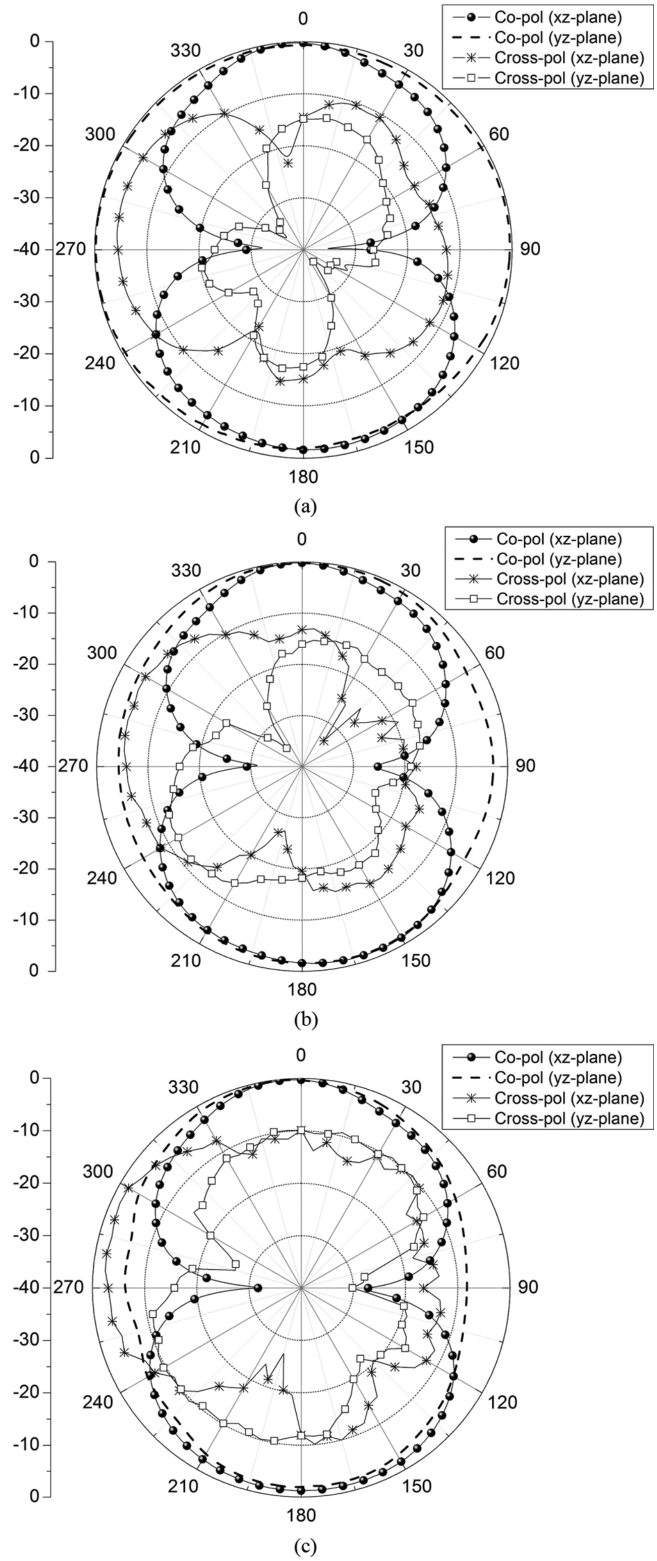

Fig. 6. Measured radiation patterns. (a) 2.4 GHz. (b) 3.5 GHz. (c) 5.2 GHz.

becomes greater in size, further increasing capacitance components. The bandwidth of the proposed antenna shows little change as s_2 increases from 10 to 14 mm. When s_2 reaches 16 mm, the resonant characteristics of f_1 become weaker, worsening the matching characteristics of the lower band. With the lowest and highest edge frequencies as the basis, f_1 stands at

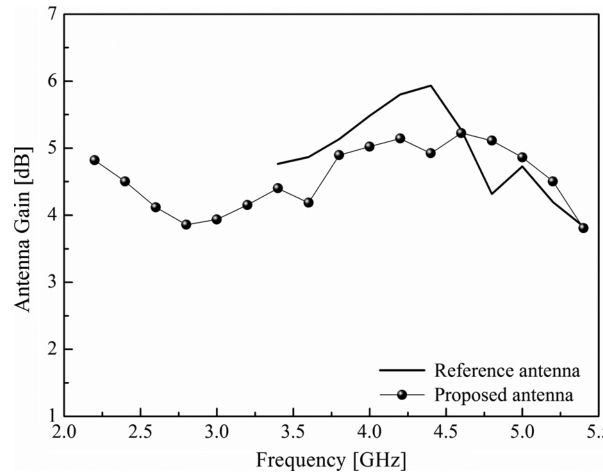

Fig. 7. Measured antenna gain.

80.6% when $s_2 = 10$ mm, 82.8% when $s_2 = 12$ mm, and 80.1% when $s_2 = 14$ mm. When one side of the center patch becomes longer, however, its matching characteristics at 3.7 GHz are deteriorated; the antenna cannot be used for broadband purposes as $|S_{11}|$ goes beyond -10 dB when s_2 reaches 14 mm. In this study, it is observed that the simulated impedance bandwidth has the widest value (3190 MHz) as the length $s_2 = 12$ mm.

IV. Simulated and Measured Results

The prototype of the proposed slot antenna with optimal geometrical parameters as shown in Fig. 1 is constructed and measured. The antenna proposed here is fabricated on commercially available FR4 substrate with $h = 1.6$ mm, $\epsilon_r = 4.4$. The geometric dimensions of the proposed antenna are as follows: $s_1 = 24.7$ mm, $s_2 = 12$ mm, $L_{\text{off}} = 3.5$ mm, and $G = 37$ mm. Fig. 5 shows measured and simulated frequency responses of reflection coefficient comparison for the proposed antenna. The measured impedance bandwidth (10-dB reflection coefficient) is as large as 3130 MHz (2225–5355 MHz) or about 82.8% with respect to the center frequency at 3790 MHz. As the ground plane decreases in size, the antenna's characteristics are affected by the SMA connector, as the separation distance between the two is close. The results deviate from those measured in the simulation where the SMA connector is not taken into account.

Radiation patterns are measured at two resonant frequencies, where the parameters of the proposed antenna are the same as those given in the above. Fig. 6 plots the measured radiation patterns. It is first seen that good omnidirectional radiation pattern is obtained. This omnidirectional characteristic is also found for the antenna excited at other frequencies across the operating bandwidth. It is also noted that radiation patterns are in symmetry with respect to the antenna axis ($\theta = 0°$) since the proposed antenna's structure is symmetrical. Fig. 7 shows the measured gain of the reference antenna and the proposed antenna.

V. Conclusion

By introducing the parasitic center patch into the rotated square slot, the impedance bandwidth of the proposed wide-slot antenna can be significantly enhanced. In addition, the size of proposed antenna can be reduced. With the optimized antenna geometry, the proposed antenna offers a measured impedance bandwidth over 80%. The proposed antenna exhibits stable far-field radiation characteristics in the entire operating bandwidth, relative high gain, and low cross polarization. By properly choosing the suitable slot shape, embedding the similar parasitic patch shape, and tuning their dimensions, the design with wide operating bandwidth, relative small size, and improved radiation pattern is obtained. It might be suitable for the 2.4/5.2-GHz WLAN application.

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