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# PROBE-FED PATCH ANTENNA WITH AN INCLINED PATCH FOR ON-WALL WLAN ACCESS POINT

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**Abstract**—A probe-fed air-substrate patch antenna with an inclined radiating patch for generating a downtilt main beam for WLAN operation in an on-wall access point is presented. The proposed antenna has a simple structure and consists of two major parts: An L-shaped ground plane and an inclined radiating patch, which is easy to implement. Constructed prototypes suitable for operating in the 2.4 GHz WLAN band are demonstrated. Results indicate that, simply by varying the inclination angle of the radiating patch, a downtilt main beam with a wide range of downtilt angles can be achieved. In addition, by selecting the proper inclination angle of the radiating patch, the proposed antenna shows a narrower 3-dB beamwidth in the elevation plane, resulting in an enhanced antenna gain, which is very suitable for on-wall 2.4 GHz WLAN access point applications. Details of the proposed antenna design are described, and experimental and simulation results are presented.

## 1. INTRODUCTION

Conventional patch antennas have some advantages of low profile, light weight, ease of fabrication and are attractive to be applied in an on-desk or on-ceiling access point inside a building for WLAN (wireless local area network) operation [1–7]. However, for the applications in an on-wall access point, the mounting patch antenna is required to be tilted toward the floor surface such that the antenna's main beam can be directed toward the mobile units to achieve enhanced performance

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for WLAN communications. However, with the tilting, the patch antenna will have an inclination angle to the mounting wall, making it aesthetically unacceptable for indoor applications. In addition, the impedance bandwidth enhancement techniques for patch antenna are also important topic. Recently, many patch antennas utilizing thick air substrates have been developed and studied to achieve the impedance bandwidth exceeding 10% defined by 2 : 1 VSWR or 5% by 1.5 : 1 VSWR for broadband operation [8–13].

Among these researches, we propose in this paper a novel and simple probe-fed air-substrate patch antenna design capable of providing a downtilt main beam, without the need of tilting the patch antenna toward the floor surface. The downtilt main beam is achieved by using an inclined radiating patch for the proposed antenna, keeping the antenna's ground plane firmly attached to the mounting wall and retaining the low-profile characteristic of the patch antenna. In the proposed design, simply by varying the inclination angle of the radiating patch, various downtilt main beams can be achieved. In addition, with a downtilt main beam achieved, the proposed antenna also shows a narrower 3-dB beamwidth in the elevation plane, resulting in an enhanced antenna gain. A 50° downtilt main beam with an antenna gain of 8.4 dBi has been obtained. Experimental and simulation results of the constructed prototypes suitable for WLAN operation in the 2.4 GHz band are presented.

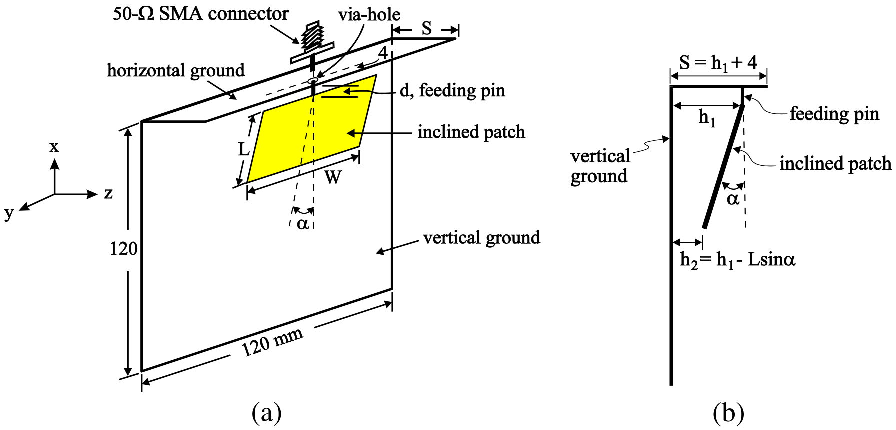



**Figure 1.** (a) Geometry of the proposed probed-fed patch antenna with an inclined patch for generating a downtilt main beam. (b) Side view of the proposed antenna in (a).

## 2. ANTENNA DESIGN

As shown in Figs. 1(a) and (b), the proposed antenna has a simple structure and consists of two major parts: An L-shaped ground plane and an inclined radiating patch. The radiating patch has a length of $L$ and a width of $W$. Note that, similar to the patch antenna with a probe feed is aligned along the antenna's radiating patch [14, 15], the proposed patch antenna is also operated as a half-wavelength structure. However, since a thick wedge-shaped air substrate is used here, which decreases the antenna's resonant length. The patch length $L$ in this study is less than 40% of the free-space wavelength for the center operating frequency. In addition, larger air substrate thickness will lead to a wider bandwidth. This characteristic makes a wider operating bandwidth to cover the 2.4 GHz WLAN band.

The L-shaped ground plane has a vertical ground (size $120 \times 120\,\text{mm}^2$ in this study) and a horizontal ground of width 120 mm and length $S$ parallel to the floor surface. The vertical ground is to be attached onto the mounting wall (in the $x$-$y$ plane in this study) for applications on an on-wall WLAN access point. The horizontal ground with a small length of 4 mm longer than the probe-pin position is used to accommodate a 50-$\Omega$ SMA connector of the probe feed, such that a minimum antenna height from the mounting wall can be achieved. In this design, good impedance matching can easily be achieved by placing the probe pin at the center of the patch edge close to the horizontal ground (a coplanar probe-fed design technique [14, 15]). In this case the probe-pin length ($d$) is usually less than 5 mm, much less than the air-layer substrate thickness, which introduces small or negligible inductance to the antenna's input impedance and thus makes it easy to achieve good impedance matching across a wide frequency range for the proposed antenna.

The inclined radiating patch has an inclination angle of $\alpha$ toward the vertical ground and is of a shape similar to that of a wedge-shaped radiating patch studied in [16]. For the case of $\alpha = 0^\circ$, the radiating patch is parallel to the vertical ground plane with a distance of $h_1$, and the patch antenna shows a main beam with maximum radiation about in the $z$ direction (parallel to the floor surface). When the angle $\alpha$ increases, the radiating patch is inclined toward the vertical ground, with the distance of the feeding patch edge to the vertical ground fixed to be $h_1$ and the distance of the other patch edge to the vertical ground decreased to be $h_2$ ($= h_1 - L \sin \alpha$). In this case the proposed patch antenna can have a downtilt main beam toward the floor surface. With various angles of $\alpha$ selected, different downtilt angles of the antenna's main beam can be achieved.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

Prototypes of the proposed patch antenna for WLAN operation in the 2.4 GHz band (2400–2484 MHz) were constructed and tested. The photograph of constructed prototype of the proposed probed-fed patch antenna ($\alpha = 30°$) is shown in Fig. 2. The measured and simulated return loss for the constructed prototype with $\alpha = 30°$ is shown in Fig. 3. The design dimensions are selected ($L = 40$ mm, $W = 60$ mm, $d = 4$ mm, $h_1 = 21$ mm) for achieving a desired wide operating bandwidth centered at about 2442 MHz. The simulated results are obtained using Ansoft HFSS (High Frequency Structure

**Figure 2.** The photograph of constructed prototype of the proposed patch antenna ($\alpha = 30°$) with an inclined patch for generating a downtilt main beam.

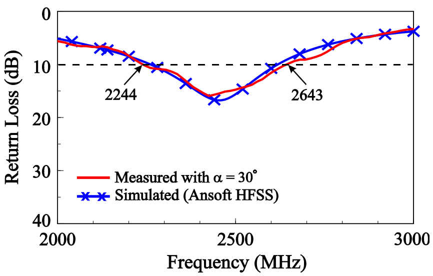



**Figure 3.** Measured and simulated return loss for the proposed antenna with $\alpha = 30°$, $h_2 = 1$ mm, $h_1 = 21$ mm, $L = 40$ mm, $W = 60$ mm, $d = 4$ mm.

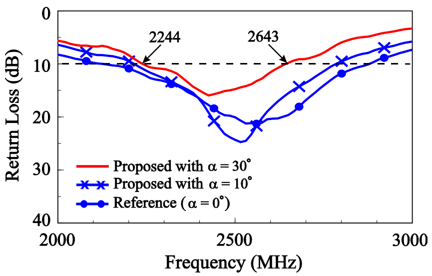



**Figure 4.** Measured return loss for the proposed antenna with $\alpha = 0°$ ($h_2 = 21$ mm), $10°$ ($h_2 = 14$ mm), $30°$ ($h_2 = 1$ mm); $h_1 = 21$ mm, $L = 40$ mm, $W = 60$ mm, $d = 4$ mm.

Simulator) simulation software [17], and good agreement between the measurement and simulation is achieved. Fig. 4 shows the measured return loss for the constructed prototypes with various inclination angles. Note that, for the cases with $\alpha = 0°$, $10°$, and $30°$ studied, the length $h_2$ equals 21 mm, 14 mm, and 1 mm, respectively. Results show that, with an increase in $\alpha$, the impedance bandwidth obtained decreases. However, for the case with $\alpha = 30°$, the impedance bandwidth obtained still reaches about 400 MHz (2244–2643 MHz or about 16% referenced to the desired center frequency 2442 MHz), easily covering the 2.4 GHz WLAN band.

Figure 5 plots the measured and simulated (by HFSS) radiation patterns for the case with $\alpha = 0°$ (the reference antenna), and the cases of the proposed antenna with $\alpha = 10°$ and $30°$ are shown in Figs. 6 and 7, respectively. The simulated 2-D radiation patterns in the $x$-$z$ and $y$-$z$ planes are shown for comparison. The measured

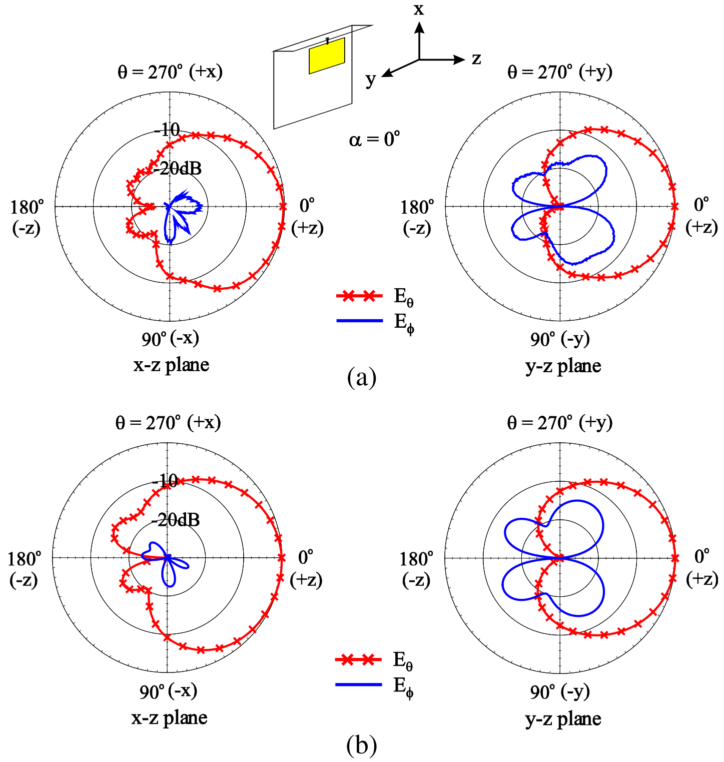



**Figure 5.** 2-D radiation patterns at 2442 MHz for the case with $\alpha = 0°$ studied in Fig. 4. (a) Measured, (b) simulated.

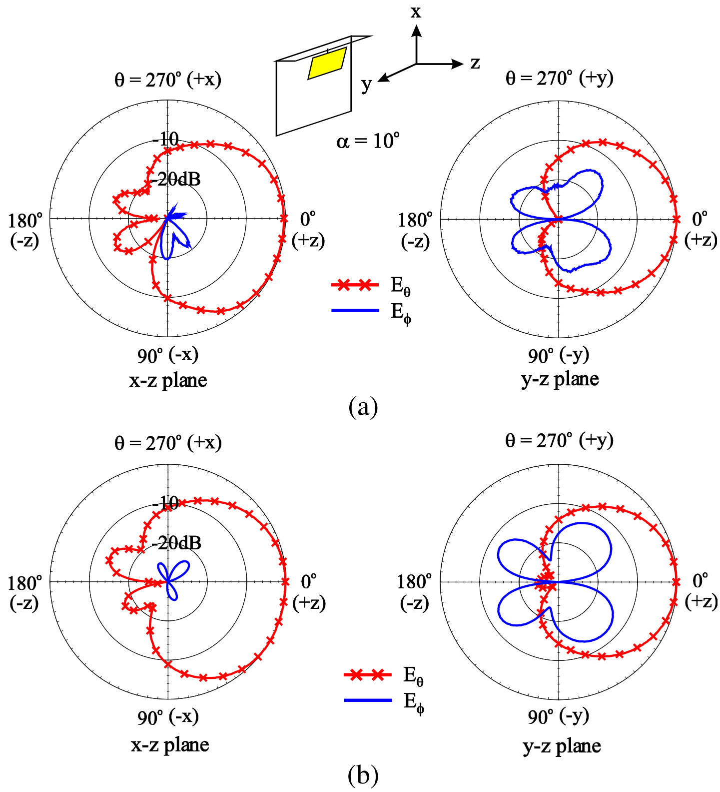



**Figure 6.** 2-D radiation patterns at 2442 MHz for the case with $\alpha = 10°$ studied in Fig. 4. (a) Measured, (b) simulated.

**Table 1.** Measured radiation performances of the cases with $\alpha = 0°$, $10°$, $20°$, and $30°$; $f = 2442$ MHz. Other parameters of the proposed antenna are the same as given in Fig. 4.

| $\alpha$ | 3-dB beamwidth in the elevation ($x$-$z$) plane | Max. radiation direction, $\theta_{max}$ | Antenna gain (dBi) |
|---|---|---|---|
| $0°$ (reference antenna) | $78°$ ($\theta = 28° \sim -50°$) | $-5°$ | 6.9 |
| $10°$ | $95°$ ($\theta = 34° \sim -61°$) | $-30°$ | 6.4 |
| $20°$ | $73°$ ($\theta = 4° \sim -69°$) | $-41°$ | 7.2 |
| $30°$ | $51°$ ($\theta = -22° \sim -73°$) | $-50°$ | 8.4 |

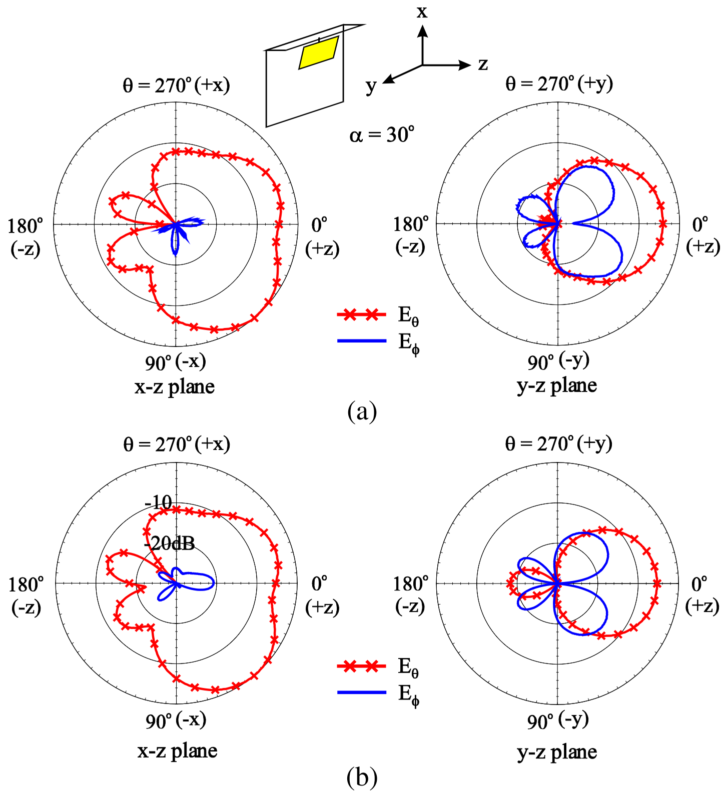



**Figure 7.** 2-D radiation patterns at 2442 MHz for the case with $\alpha = 30^\circ$ studied in Fig. 4. (a) Measured, (b) simulated.

data are generally in agreement with the simulated results. The corresponding measured data are also listed in Table 1 for comparison. It is clearly seen that the measured patterns are downtilted toward the $-x$ direction or the floor surface with an increase in $\alpha$. For the case with $\alpha = 30^\circ$, the downtilt angle or the maximum radiation direction ($\theta_{\max}$) of the measured radiation patterns reaches as large as $-50^\circ$, suggesting that a large adjustable downtilt angle of the antenna's main beam can be achieved by varying the inclination angle $\alpha$. In addition, the 3-dB beamwidth becomes narrower for the cases with $\alpha = 20^\circ$ and $30^\circ$, and an enhanced antenna gain is achieved (7.2 and 8.4 dBi vs. 6.9 dBi). In addition, Figs. 8–10 give the measured and simulated (by HFSS) 3-D radiation patterns at 2442 MHz for the cases with $\alpha = 0^\circ$, $10^\circ$, and $30^\circ$, respectively. Good agreements between the measurement and simulation results are seen. The measured far-

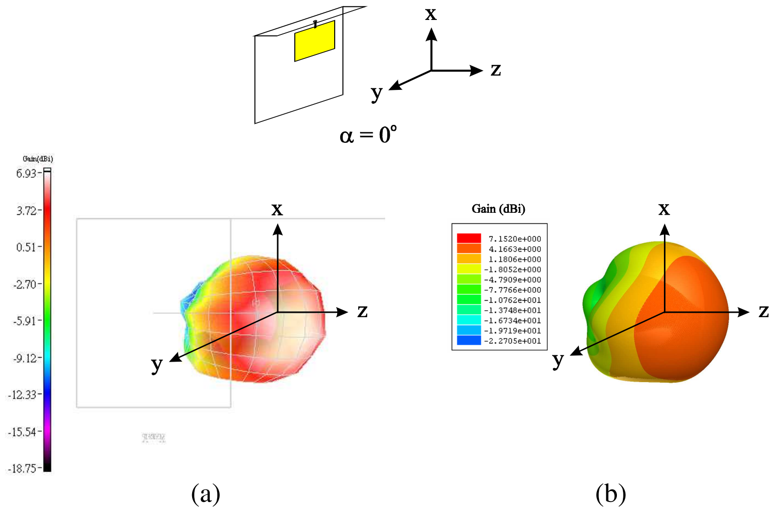



**Figure 8.** 3-D radiation patterns at 2442 MHz for the case with $\alpha = 0°$ studied in Fig. 4. (a) Measured (b) simulated.

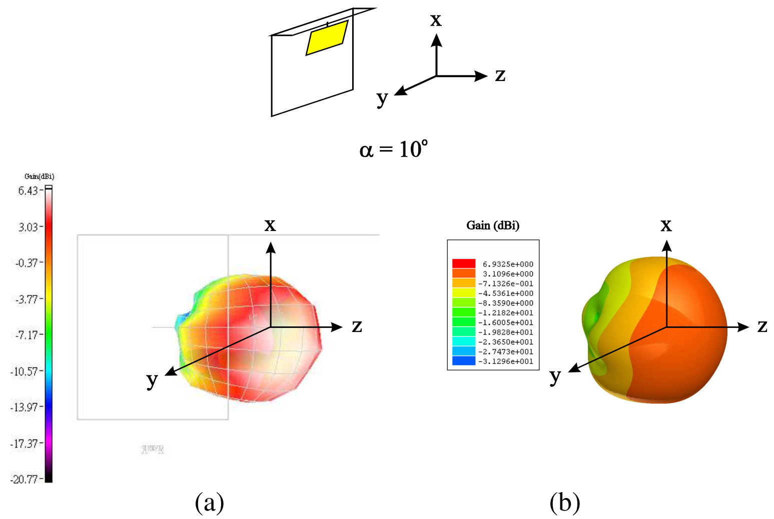
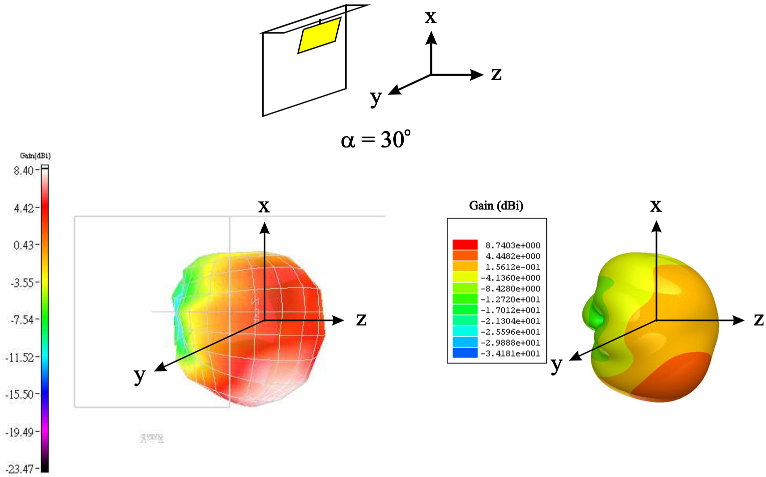



**Figure 9.** 3-D radiation patterns at 2442 MHz for the case with $\alpha = 10°$ studied in Fig. 4. (a) Measured (b) simulated.




(a) (b)

**Figure 10.** 3-D radiation patterns at 2442 MHz for the case with $\alpha = 30^\circ$ studied in Fig. 4. (a) Measured (b) simulated.

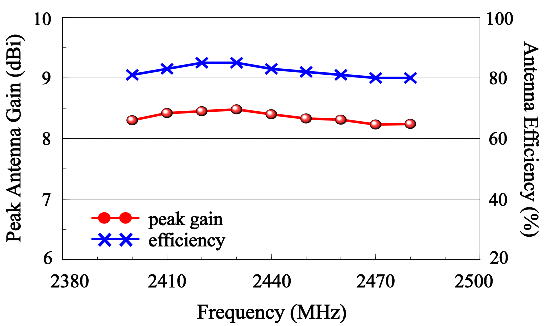



**Figure 11.** Measured antenna gain and radiation efficiency for the case with $\alpha = 30^\circ$ studied in Fig. 4.

field 3D radiation patterns are measured at a fully anechoic chamber (dimensions $7.3 \times 4 \times 3.6\,\text{m}^3$) at R.O.C. Military Academy. The 3D measurement system uses the great-circle method and is equipped with a dual-polarized horn as a receiving antenna. The measurements for other frequencies across the 2.4 GHz band were also studied, and the measured results showed similar radiation patterns as plotted here. The measured antenna gain and radiation efficiency of the proposed antenna with $\alpha = 30^\circ$ for frequencies across the 2.4 GHz band is also presented in Fig. 11. The measured antenna gain for the proposed antenna ($\alpha = 30°$) is about 8.4 dBi, which is about 1.5 dBi higher than that of the reference antenna ($\alpha = 0°$, listed in Table 1). This gain enhancement is largely due to the narrower 3-dB beamwidth in the elevation plane for the proposed antenna, as compared to the reference antenna. Good radiation efficiency is also obtained, and it is found to be in the range of about 80–85% from the measured results.

## 4. CONCLUSION

A probe-fed patch antenna with an inclined radiating patch for achieving a downtilt main beam has been proposed. The proposed antenna has a simple structure and is easy to implement. Experimental and simulation results have been presented. Results show that, simply by varying the inclination angle of the radiating patch of the proposed antenna, various downtilt main beams can be achieved. With a downtilt main beam achieved, the proposed antenna also shows a narrower 3-dB beamwidth in the elevation plane, resulting in an enhanced antenna gain. Note that, for the on-wall WLAN access point applications, without the need of tilting the patch antenna toward the floor surface are also obtained. In addition, a wide impedance bandwidth is easily achieved for the proposed antenna. With the attractive radiation performance obtained, the proposed patch antenna is very suitable for applications in an on-wall WLAN access point.

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