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HIGH-GAIN SLOT ANTENNA WITH PARASITIC PATCH AND WINDOWED METALLIC SUPERSTRATE

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Abstract—In this paper, a directional slot antenna with parasitic patch and windowed superstrate is presented. Through this composition, high-gain property can easily be obtained by this proposed antenna. The proposed antenna has a measured impedance bandwidth of 2.41–2.49 GHz for $S_{11} < -10$ dB, which can cover the 2.4–2.484 GHz frequency band of WLAN application. Simulated and measured results show that high-gain features up to 11.50 dBi across the corresponding impedance band are achieved. Details of the proposed slot antenna configurations and design procedures are given; the experimental results are also given and discussed.

1. INTRODUCTION

Microstrip-fed slot antennas (MFSA) offer many attractive features such as low profile, high power capacity, high fabrication tolerance, and ease of integration with printed circuits. Thus they are mostly and popularly used in military (aircraft, spacecraft, and missile) and commercial (mobile radio and wireless communications) applications [1–7]. However, they still suffer from the disadvantages of bi-directional radiation, low gain and would not be suitable for some applications, such as point-to-point (p2p) communications.

To overcome some of the above problems of the microstrip-fed slot antenna, many gain-enhancement techniques have been proposed and discussed. The most common way is to place a metallic cavity backing the slot antenna to achieve a unidirectional radiation [8–13]. But these cavities occupy a large scale and are not beneficial for the miniaturization of the system. A microstrip slot antenna

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backed by a super-low cavity was proposed to reduce the height of cavity greatly [14]. Besides, using a reflector backing the slot is also a useful way for high-gain operation [15], but it still occupies a large scale. Another useful method was proposed by the authors in [16, 17], where the unidirectional radiation can be easily obtained by using a pair of parasitic patches printed symmetrically to the feeding line. And in [18], a dielectric superstrate was placed above the cavity-backed slot antenna (CBS), and a gain up to 7.0 dB at the frequency of 5.75 GHz has been achieved. However, the gains of the antennas [8–18] mentioned above may still not be large enough for the p2p application. In our previous works [19, 20], a windowed metallic superstrate was placed above the CBS, and by properly adjusting the height of the superstrate and size of the window, gains larger than 11.5 dBi were attained across the impedance bands of 2.35–2.55 GHz. Notwithstanding, the profiles of these two antennas are still too large, and the fabrication and installation of the cavity are not convenient.

In this paper, a novel low-profile, high gain slot antenna is proposed and discussed. The slot antenna is firstly designed as one and a half wavelength long. Then, by use of the parasitic patches printed symmetrically to the feeding line, the bi-directional radiation feature is changed into unidirectional with gain enhanced. Finally, for the purpose of further enhancing the antenna gain, a windowed metallic superstrate is placed above the slot, thus, the antenna gain is strongly enhanced, and a simulated peak gain of 12.45 dBi is shown. Both the mechanisms of high gain and characteristics of some key parameters of the structure are also given and discussed in this paper.

2. ANTENNA CONFIGURATIONS AND DESIGN ANALYSIS

The configurations of the proposed slot antenna are shown in Figure 1. The antenna is built on a substrate with a dielectric constant of 2.55 and a height of $h_1 = 0.8$ mm, and the total size is 160 mm × 170 mm with the substrate length $a = 160$ mm and width $b = 170$ mm. As shown in Figure 1, from bottom to top, the components of the antenna are listed as follows: microstrip feeding line printed on the bottom side of the substrate, a pair of patches printed at the same side and symmetrically with respect to the feeding line, a long rectangular slot etched on the top side of the substrate as the radiating element, and a rectangular metallic superstrate with a window cut placed above the $fedw = 2.2$ mm is extended around one-quarter waveguide length at 2.45 GHz from the center of the slot and acts as a shorting feed for the slot. The parasitic patches with an equal width and length of

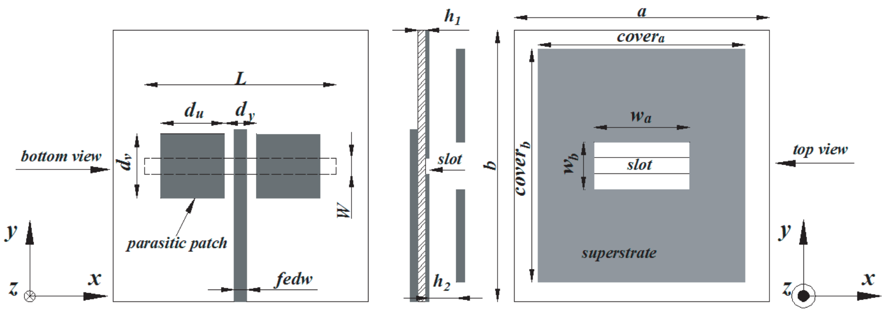


Figure 1. Configurations of the proposed slot antenna.

$d_u = d_v = 40$ mm are placed a distance of $d_y = 18$ mm from each other, and the size of the slot is width $W = 3$ mm, length $L = 120$ mm. The distance to the superstrate from the slot is $h_2 = 6$ mm. The windowed superstrate occupies an area of 150 mm × 146 mm, with a superstrate length $cover_a = 150$ mm and width $cover_b = 146$ mm. The window size is 60 mm × 24 mm, where the length is $w_a = 60$ mm, and the width is $w_b = 24$ mm, respectively.

According to [17], the length of the slot is firstly chosen as one and a half waveguide length, and the width and length of the parasitic patches are picked to be half the waveguide length. Therefore, for the case of 2.45 GHz WLAN application, the corresponding parameters of the slot and parasitic patches are selected as $L = 120$ mm, $d_u = d_v =$ 40 mm.

The high gain mechanisms of the proposed slot antenna are based on the following approaches.

The slot electric field perpendicular to the slot length has a standing wave distribution with positive and negative nodes along its axis. And the direction of the electric field is reversed after propagating over a half-wavelength. Thus, there would be three standing waves along the proposed slot antenna because of its one and a half wavelength, where one positive peak voltage is located at the center of the slot while the other two are negative ones located half wavelength away from the center. Thus by sliding the parasitic patches along the slot axis, the center of the patch can be moved close to the negative peak voltage, and will force partial power into the front half-space with a reverse phase with the remaining ones feeding the patch. Therefore, the front radiation of the slot can be partially enhanced and the parasitic patches produce a radiated field over the back region of the substrate. By properly adjusting the dimensions and the relative positions of the slots and the patches, the magnitude of the total radiation fields in the back space can be partially cancelled due to approximately 180 degrees out of phase from the slot and parasitic patches.

While for the windowed metallic superstrate, it can be viewed as a director which further enhances the radiation in the front space. Based on our previous work [19, 20], the windowed area can be taken as an antenna aperture, where the tangential electric fields are uniform and larger than the normal ones. Moreover, the electric fields at the window fringe and the margin of the superstrate are in-phase if the size is properly selected and both sides of the superstrate can be viewed as two air-filled microstrip patch antennas. Thus, the radiation in the front-space of the slot will be greatly enhanced and the high-gain operation is acquired.

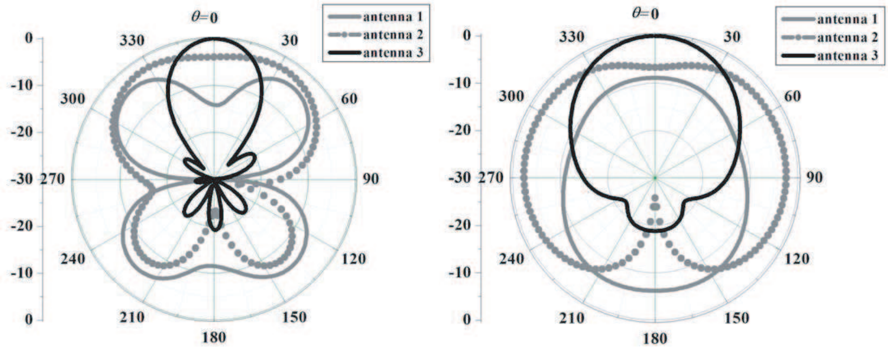
In summary, there are three key points for the design of the proposed antenna: 1. The slot has a length of around one and a half waveguide length. 2. The width and the length of the parasitic patch are chosen equal and with half the waveguide length. 3. The distance from the window fringe to the edge of the same side of the superstrate is approximately half a waveguide length.

3. PARAMETRIC STUDY AND DISCUSSION

With the use of EM simulator Ansoft HFSS, the proposed slot antenna is modeled and simulated. The optimized parameters are listed as: $h_1 = 0.8\,\mathrm{mm}$, $a = 160\,\mathrm{mm}$, $b = 170\,\mathrm{mm}$, $d_u = 40\,\mathrm{mm}$, $d_v = 40\,\mathrm{mm}$, $h_2 = 6\,\mathrm{mm}$, $L = 120\,\mathrm{mm}$, $W = 3\,\mathrm{mm}$, $d_y = 18\,\mathrm{mm}$, $cover_a = 150\,\mathrm{mm}$, $cover_b = 146\,\mathrm{mm}$, $w_a = 60\,\mathrm{mm}$, $w_b = 24\,\mathrm{mm}$.

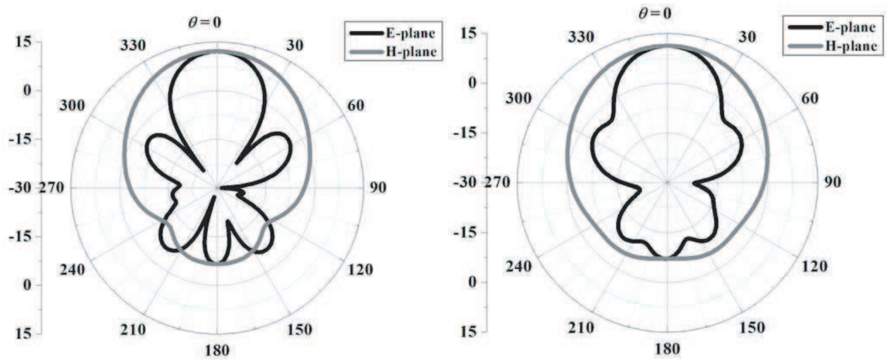
Figure 2 depicts the simulated radiation patterns in the E-plane and H-plane for different cases. Antenna 1 indicates the slot antenna where the superstrate and parasitic patches are both eliminated from the proposed design. Antenna 2 means the antenna design where only the metallic superstrate is excluded, while antenna 3 is the proposed design. From the simulated results, we can see that antenna 1 shows a bidirectional radiation with two broad main lobes. The introduction of the parasitic patches cancel the back radiation and the front-space radiation is enhanced. In addition, the draw of the windowed metallic superstrate further increases the radiation of the front-space. It is seen that there is only one narrow beam in E-plane and no back radiation in the back region of H-plane.

It can be concluded from Section 2 that the distance d_y has significant effects on the radiation enhancements. Thus, the radiation patterns against different d_y is simulated and shown in Figure 3, while

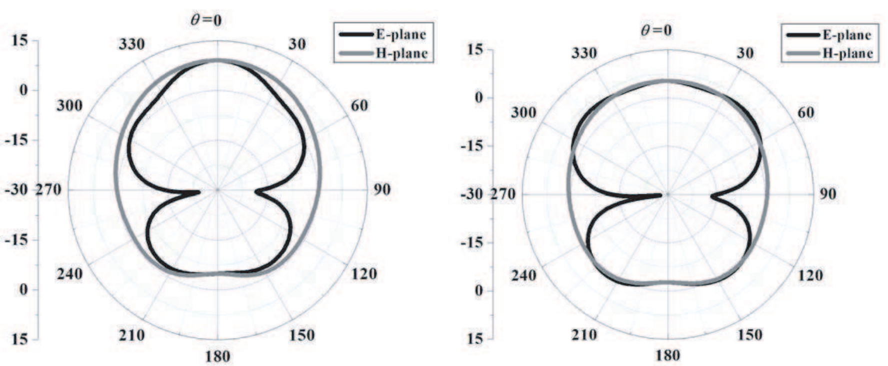


(a) E-plane radiation patterns (b) H-plane radiation patterns

Figure 2. Simulated radiation patterns of different antenna structures.



(a) d_y = 15 mm (b) d_y = 25 mm



(c) d_y = 35 mm (d) d_y = 45 mm

Figure 3. The simulated radiation patterns with different d_y.

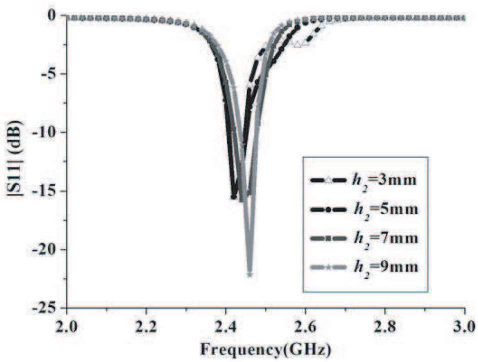


Figure 4. The simulated S-parameters against different superstrate height of h_2.

other parameters are fixed. From the simulated results, it is obviously seen that as the d_y parameter increases, the main lobe enlarges and the high-gain characteristic degrades. As plotted in Figure 3(c), if the distance d_y is large to a certain degree, the back lobe becomes big and is equal to the main lobe. Therefore, d_y should be carefully adjusted to maintain the high-gain operation.

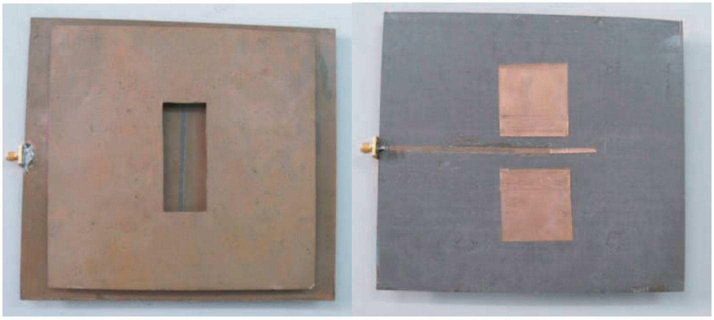
The simulated S-parameter results against different h_2 are also studied and demonstrated in Figure 4. From this figure, we can see that the parameter h_2 has some effect on the impedance matching of the proposed slot antenna and should be properly adjusted.

4. MEASURED RESULTS

To verify our design method, a prototype antenna has been fabricated and tested. The fabricated antenna photos are shown in Figure 5.

The simulated and measured S-parameter results are contrasted in Figure 6, and it is seen that these two results are well matched. The measured result shows that the proposed antenna has a measured impedance bandwidth of 2.41–2.49 GHz with $S_{11} < -10$ dB. The variation may probably come from the manufacturing errors. Hence, the antenna can cover the 2.40–2.484 GHz frequency band of WLAN.

Figure 7 plots the measured radiation patterns of E-plane and H-plane at 2.45 GHz. It is obvious that the measured ones and simulated ones are in quite good agreement. The measured E-plane radiation pattern shows that the proposed antenna has only one narrow main lobe in the front region with the front-back ratio equaling to 17 dB. Figure 7(b) shows that the proposed antenna has a 3 dB beam width larger than 60 degrees and almost no back lobes in its H-plane.



(a) (b)

Figure 5. Photos of the proposed antenna: (a) top view, (b) bottom view.

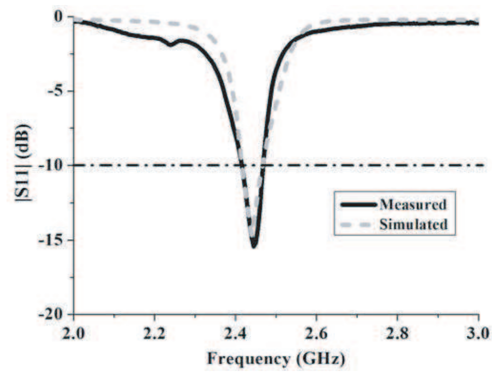


Figure 6. The measured and simulated S-parameters of the proposed antenna.

Figure 8 portrays the measured peak gain of the proposed slot antenna across the impedance bandwidth from 2.35 GHz to 2.55 GHz. As shown in this figure, the proposed antenna can achieve high gain up to 11.5 dBi, with the maximum gain of 12.45 dBi at the center frequency of 2.45 GHz. During the test, it is found that outside the matching bandwidth, that is for frequencies rather larger than 2.55 GHz or smaller than 2.35 GHz, the high gain feature degrades sharply. Therefore the proposed design has the ability of rejecting interference from other application bands.

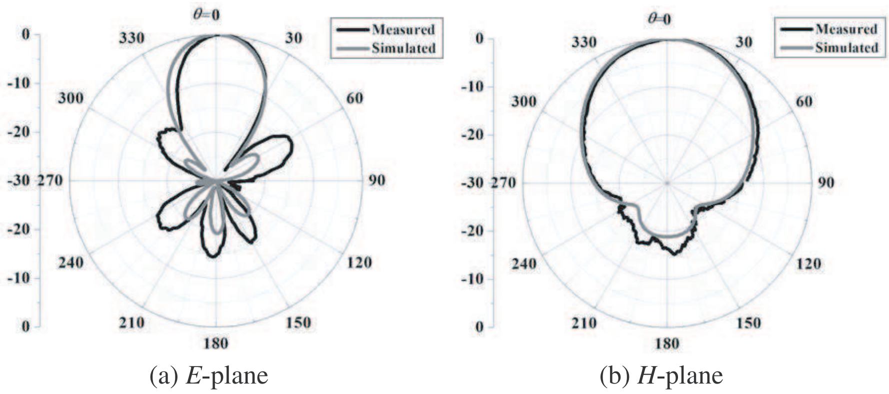


Figure 7. The measured and simulated radiation patterns at 2.45 GHz.

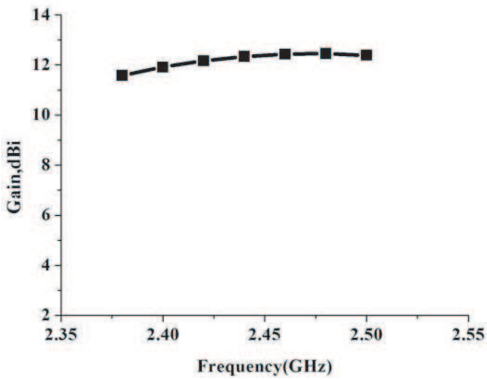


Figure 8. Measured peak gains of the proposed slot antenna.

5. CONCLUSION

A high-gain slot antenna with parasitic patches and windowed metallic superstrate is presented in this paper. With the use of two parasitic patches and a windowed metallic superstrate, the radiations in the front-space are greatly enhanced. A measured bandwidth of 2.41–2.49 GHz and peak gains up to 12.45 dBi are obtained by the proposed slot antenna. Because of its high-gain and low-profile, the proposed slot antenna can find many applications in wireless p2p communication systems.

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REFERENCES

1. Sharma, S. K., L. Shafai, and N. Jacob, "Investigation of wide-band microstrip slot antenna," *IEEE Trans. Antennas and Propagation*, Vol. 52, No. 3, 865–872, 2004.
2. Sharma, S. K., N. Jacob, and L. Shafai, "Low profile wide band slot antenna for wireless communications," *Proc. IEEE AP-S Int. Symp.*, Vol. 1, 390–393, 2002.
3. Sabri, H. and Z. Atlasbaf, "Two novel compact triple-band microstrip annular-ring slot antenna for PCS-1900 and WLAN applications," *Progress In Electromagnetics Research Letters*, Vol. 5, 87–98, 2008.
4. Gao, G.-P., M. Li, S.-F. Niu, X.-J. Li, B.-N. Li, and J.-S. Zhang, "Study of a novel wideband circular slot antenna having frequency band-notched function," *Progress In Electromagnetics Research*, Vol. 96, 141–154, 2009.
5. Mahatthanajatuphat, C., P. Akkaraekthalin, S. Saleekaw, and M. Krairiksh, "Bidirectional multiband antenna with modified antenna with modified fractal slot fed by CPW," *Progress In Electromagnetics Research*, Vol. 95, 59–72, 2009.
6. Ren, W., "Compact dual-band slot antenna for 2.4/5 GHz WLAN applications," *Progress In Electromagnetics Research B*, Vol. 8, 319–327, 2008.
7. Eldek, A. A., A. Z. Elsherbeni, and C. E. Smith, "Design of wideband triangle slot antennas with tuning stub," *Progress In Electromagnetics Research*, Vol. 48, 233–248, 2004.
8. Eldesouki, E. M. A., K. F. A. Hussein, and A. M. El-Nadi, "Circular polarized arrays of cavity backed slot antennas for X-band satellite communications," *Progress In Electromagnetics Research B*, Vol. 9, 179–198, 2008.
9. Zheng, B. Y. and Z. X. Shen, "Effect of a finite ground plane on microstrip-fed cavity-backed slot antennas," *IEEE Trans. Antennas and Propagation*, Vol. 53, No. 2, 862–865, 2005.
10. Leung, K. W. and K. Y. Chow, "Theory and experiment of the hemispherical cavity-backed slot antenna," *IEEE Trans. Antennas and Propagation*, Vol. 46, No. 8, 1234–1241, 1998.
11. Li, Q., Z. X. Shen, and P. T. Teo, "Microstrip-fed cavity-backed

slot antennas," *Microwave Opt. Technol. Lett.*, Vol. 33, No. 4, 229–233, 2002.

12. Li, Q. and Z.-X. Shen, "An inverted microstrip-fed cavity-backed slot antenna for circular polarization," *IEEE Antennas Wireless Propag. Lett.*, Vol. 1, 190–192, 2002.
13. Qu, S.-W., J.-L. Li, Q. Xue, and C. H. Chan, "Novel unidirectional slot antenna with a vertical wall," *Progress In Electromagnetics Research*, Vol. 84, 239–251, 2008.
14. Vallecchi, A. and G. B. Gentili, "Microstrip-fed slot antennas backed by a very thin cavity," *Microwave Opt. Technol. Lett.*, Vol. 49, No. 1, 247–250, 2007.
15. Chair, R., A. A. Kishk, K.-F. Lee, C. E. Smith, and D. Kajfez, "Microstrip line and CPW fed ultrawideband slot antennas with U-shaped tuning stub and reflector," *Progress In Electromagnetics Research*, Vol. 56, 163–182, 2006.
16. Rao, Q., T. A. Denidni, and R. H. Johnston, "A single-substrate microstrip-fed slot antenna array with reduced back radiation," *IEEE Antennas Wireless Propag. Lett.*, Vol. 3, 265–268, 2004.
17. Rao, Q., T. A. Denidni, and R. H. Johnston, "A new aperture coupled microstrip slot antenna," *IEEE Trans. Antennas and Propagation*, Vol. 53, No. 9. 2818–2826, 2005.
18. Tan, W. H., Z. X. Shen, Z. H. Shao, et al., "A gain-enhanced microstrip-fed cavity-backed slot antenna," *IEEE Asian Pacific Microwave Conference Suzhou*, Vol. 1–5, 789–792, 2005.
19. Ma, H. Q., Q.-X. Chu, and Q. Zhang, "High gain cavity-backed slot antenna with a windowed metallic superstrate," *Microwave Opt. Technol. Lett.*, Vol. 50, No. 12, 3114–3118, 2008.
20. Zhang, Q.-Y. and Q.-X. Chu, "Triple-band cavity-backed Z-like slot antenna for WLAN applications," *Microwave Opt. Technol. Lett.*, Vol. 51, No. 10, 2296–2301, 2009.