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A Compact Broadband Slot Antenna for Indoor Distributed Antenna Systems

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Abstract—A compact omnidirectional vertical-polarized broadband slot antenna for indoor distributed antenna systems is presented. The proposed antenna consists of a deformed printed monopole on one side of the substrate and a polygon slot in the circular ground plane on the other side. Due to the utilization of the wideband slot structure, the antenna achieves small electrical dimension of $0.327\lambda \times 0.327\lambda \times 0.0046\lambda$ at the lowest operating frequency, and an impedance bandwidth of about 129% (0.66–3.07 GHz) for VSWR $\leq$ 1.5 is achieved, covering all frequency bands for 2G, 3G, 4G and some Wi-Fi communications. The proposed antenna has stable radiation patterns over the operating bands. The measured gains of the antenna range from 1.5 dBi (lower band) to 5.5 dBi (higher band). Compact planar structure makes the proposed antenna a perfect candidate for ceiling or surface mounted indoor distributed antenna applications.

1. INTRODUCTION

In recent years, with the rapid development of communication systems, indoor distributed antenna system plays a crucial role in wireless communication systems. Wireless signal coverage is provided by outdoor stations when communication systems spread widely. However, the coverage is not satisfactory due to high signal losses caused by the building walls. Therefore, indoor distributed antenna system was first proposed for GSM and CDMA, nowadays known as multiservice indoor distributed antenna system [1]. As the most significant component in indoor distributed antenna system, broadband antennas have many advantages such as large bandwidth, compact size, and lightweight structure, thus they are used to support higher quality and multiservice. Since more wireless coverage networks will be built, more indoor broadband antennas are needed in the near future.

Several relevant antennas have been designed in the literature. The planar monopole antenna [2] for multi-band wireless system provides an impedance bandwidth beyond about 100% for VSWR ≤ 2. A $\lambda/14.7$-tall wideband monocone antenna [3] has a 3 : 1 bandwidth. However, the antennas [2, 3] have narrow bandwidth. By using the tapered structure element and shoring pins to the ground plane, sleeve monopoles with enhanced impedance bandwidths of about 112% ranging from 750 to 2660 MHz (VSWR $\leq$ 2) and of about 137% from 730 to 3880 MHz (VSWR $\leq$ 2) for indoor base station application are presented in [4, 5], respectively. Omnidirectional ultra-wideband antennas with monopole-like radiation characteristics are reported in [6, 7]. However, these types of antennas are generally large in size, in order to maintain impedance and radiation pattern performance over a wide frequency range. In [1], a broadband dipole antenna for multiservice indoor distributed antenna system is presented to cover the mobile services within 880–2700 MHz. However, all these antennas have complex structures. A simple compact antenna covering the whole indoor communication bands is expected.

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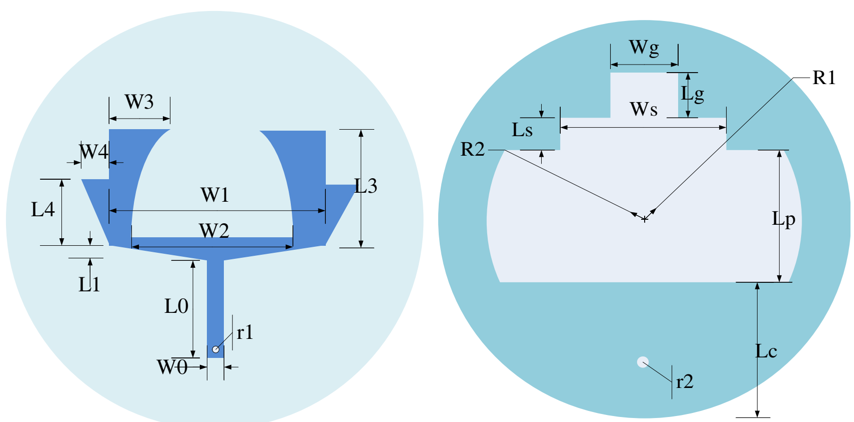
Over the past decade, planar wide slot antennas have attracted much attention due to their advantages such as wide band radiation performance [8–13]. As reported in [14], the wider the antenna slot is, the larger the impedance bandwidth is. For this purpose, a novel type of vertical-polarized broadband slot antenna is presented for indoor distributed antenna systems in this letter, and its size is greatly reduced due to the planar slot structure. The impedance bandwidth of this antenna ranges from 0.66 to 3.07 GHz (VSWR $\leq$ 1.5), covering all frequency bands for 2G, 3G, 4G and some Wi-Fi communications. The antenna has stable, omnidirectional radiation pattern in its H-plane. Details of the antenna design with simulated and measured results are introduced in the following sections to demonstrate performance of the proposed antenna.

2. DESIGN AND ANALYSIS OF PROPOSED ANTENNA

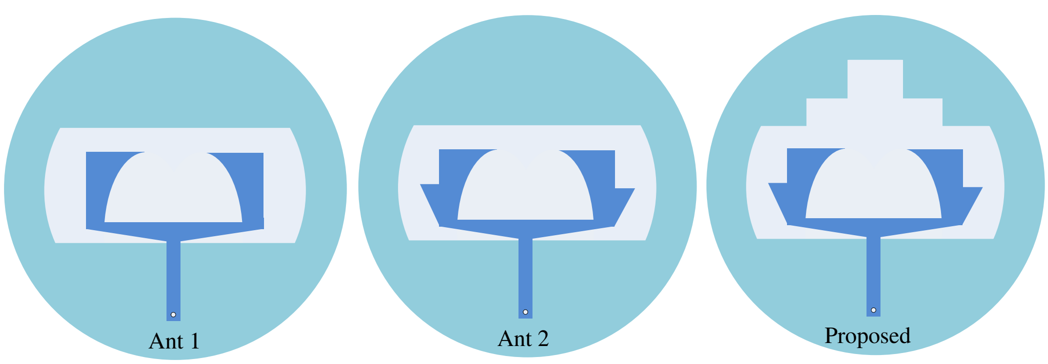
Geometry of the designed broadband antenna is shown in Fig. 1. The antenna is fabricated on both sides of a circular FR4 substrate with radius of 70 mm, thickness of 2 mm, relative permittivity of 4.4, and loss tangent of 0.02. The radiating element consists of a deformed monopole printed on the top side of the substrate, and a polygon slot in the circular ground on the bottom side. The antenna is fed by a 50-Ω coaxial cable connected to microstrip line through a via. Figs. 1(a) and (b) show the top and bottom views of the proposed antenna.

To demonstrate the operating principle clearly, Fig. 2 shows the design procedure of the proposed



(a) (b)

Figure 1. Geometry of the antenna. (a) Top view, (b) bottom view (Blue metal in front, and green metal in bottom).



(a) (b) (c)

Figure 2. Design procedure of the proposed antenna. (a) Ant 1, (b) Ant 2, and (c) proposed antenna.

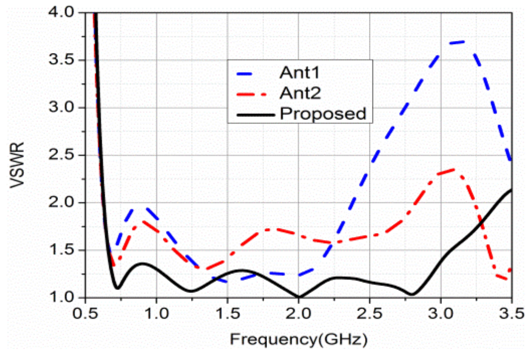


Figure 3. Simulated VSWRs for different antennas.

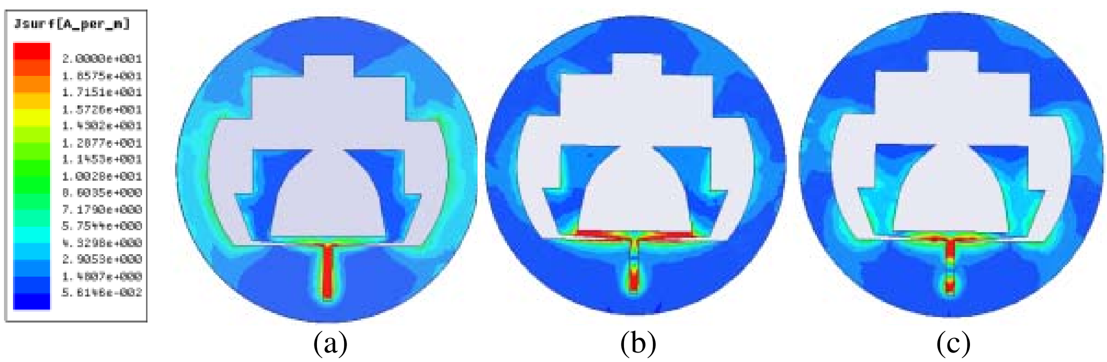


Figure 4. Simulated surface current distributions. (a) $f = 0.7\,\mathrm{GHz}$, (b) $f = 2.0\,\mathrm{GHz}$, and (c) $f = 2.7\,\mathrm{GHz}$.

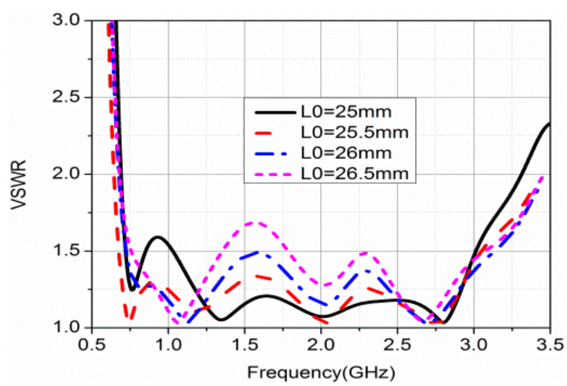


Figure 5. Simulated VSWR curves with different L_0's.

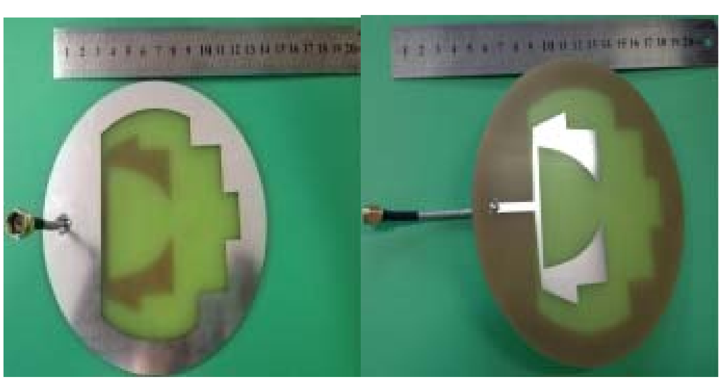
broadband antenna, and Fig. 3 presents Ant1, Ant2 and the proposed antenna's simulated VSWR results. As shown in Fig. 3, Ant 1 covers the higher band 1.3–2.2 GHz, and the lower band resonates at 0.7 GHz. Compared with Ant 1, two triangles are added on double sides of the deformed monopole in Ant 2, producing a new resonant frequency at 2.7 GHz. The VSWRs of Ant 2 are lower than 2.0 in the frequency band of 0.6–2.7 GHz. At lower and higher frequency bands, the VSWRs of Ant 2 are less than the VSWRs of Ant 1, and in the middle frequency band, the VSWRs of Ant 2 are a little bigger than the VSWRs of Ant 1. Their variation gets smooth, and Ant 2 is more likely to have broadband feature. In order to further improve the impedance matching of the antenna, two sequential rectangular slots are etched in the ground plane. As shown in Fig. 3, with the introduction of two slots, the proposed antenna covers a broad operating band from 0.66 to 3.07 GHz (VSWR $\leqslant 1.5$). In order to clarify the radiation characteristic of the proposed antenna, simulated current distributions are shown in Fig. 4. Obviously, in the lower frequency band, the currents distribute around edge of the circular ground, so parameters R_1 and R_2 determine the lowest frequency, which is beneficial to reducing the overall size of the antenna. Moreover, currents on the bottom of the monopole corresponds to the medium and higher frequency bands; therefore, parameters L_0 and W_1 have a lager influence on their resonant frequencies generated by the slot. As a result, the presented antenna can cover the frequency band of 0.66–3.07 GHz, which supports most of the wireless communication frequency bands.

For the designed antenna, we require VSWR $\leqslant 1.5$ in the operating band, which may be achievable by adjusting some parameters of the antenna. Experimental results for wide-band printed wide slot antennas [8] show that their impedance matching is greatly affected by the feed gap width. Note that the distance between the monopole and the ground is determined by parameter L_0. Fig. 5 shows simulated VSWR curves with different L_0. As shown, the antennas exhibit an operating band of 0.7–3 GHz with VSWR $\leqslant 1.5$. When L_0 varies from 25 mm to 26.5 mm, the VSWRs increase at the higher frequencies, but it has a little influence on lower frequencies except $L_0 = 25$ mm. After optimization, we choose $L_0 = 25.3$ mm.

For the limited space, analysis results for other parameters are not provided. All the structure parameters of the antenna are optimized by using the High Frequency Structure Simulator (HFSS) ver.15. The final structure parameter values for the antenna are listed in Table 1.

Table 1. Structural parameters of the presented antenna.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
R_1	70	L_2	2	L_7	5
R_2	55	W_2	53	L_8	7.8
r_1	0.5	L_3	40	L_c	35
r_2	1.5	W_3	28	L_p	60
L_0	25.3	L_4	20	L_s	19.5
W_0	3.88	W_4	8	W_s	71
L_1	2	L_5	16	L_g	10
W_1	70	L_6	20	W_g	23.5
t	2.15				



(a) (b)

Figure 6. Prototypes of the broadband antenna. (a) Top view, (b) backside view.

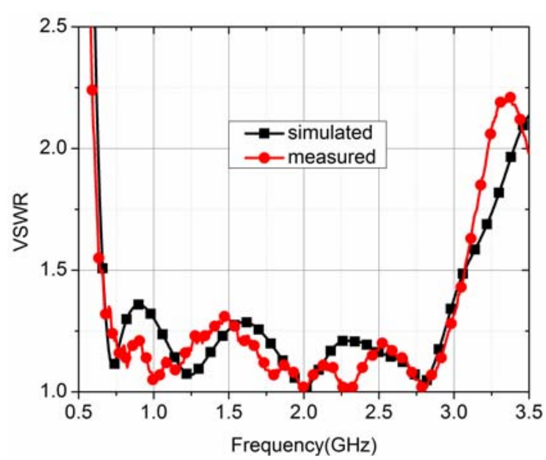


Figure 7. Measured and simulated VSWRs.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The antenna is fabricated on a double-side FR-4 substrate. A prototypes of the broadband antenna is presented in Fig. 6. Measured and simulated VSWRs for the antenna are shown in Fig. 7. From the figure, we can see that the antenna covers the band 0.69–3.10 GHz (VSWR ≤ 1.5). The measured results agree well with the simulated ones. The discrepancy between simulated and measured results is mainly due to the fabrication tolerances and feeding coaxial cable to line transition.

Measured and simulated co- and cross-polarization radiation patterns at 806, 2025 and 2690 MHz are shown in Fig. 8. It is obvious that the antenna exhibits almost omnidirectional radiation pattern

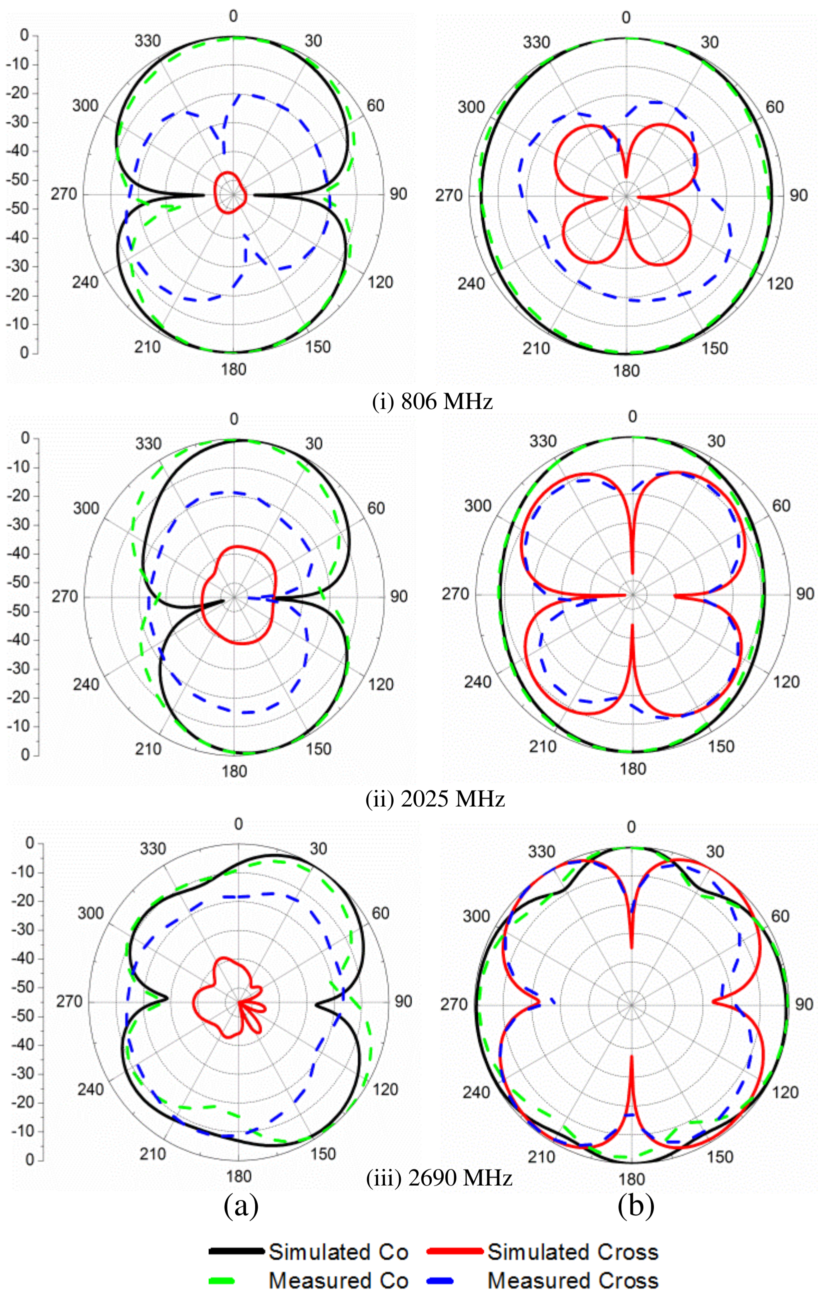


Figure 8. Simulated and measured co- and cross-polarization radiation patterns of the antenna. (a) E-plane (xoz-plane), and (b) H-plane (yoz-plane). (i) 806 MHz, (ii) 2025 MHz, and (iii) 2690 MGHz.

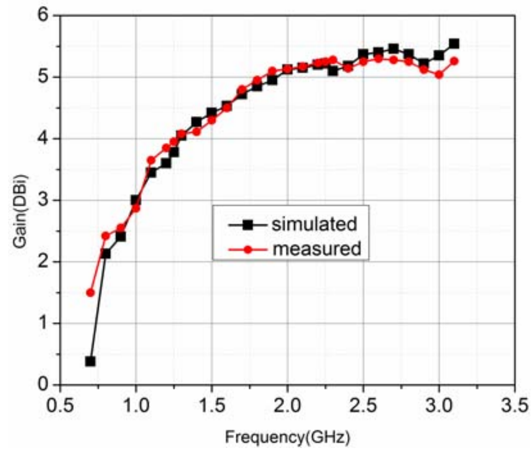


Figure 9. Simulated and measured gains of the antenna.

Table 2. Compararison of proposed antennas with some existing antenna in the references.

Antenna	Bandwidth (MHz)	Dimension (Unit: mm)	Gain (dBi)
[1]	880–2700 (VSWR ≤ 2)	$180 \times 150 \times 50$	6.5–9.0
[3]	800–2400 (VSWR ≤ 2)	$\Phi 126 \times H25.4$	1.7–9.0
[4]	750–2662 (VSWR ≤ 2)	$\Phi 150 \times H29$	1.5–1.9
[5]	730–3880 (VSWR ≤ 2)	$\Phi 150 \times H30$	2.5–6.7
[6]	1000–4000 (VSWR ≤ 3)	$70 \times 70 \times 10$	2.0–5.0
[7]	650–6000 (VSWR ≤ 1.5)	$\Phi 90 \times H105$	1.9–5.0
Proposed	660–3050 (VSWR ≤ 1.5)	$\Phi 70 \times H2$	1.5–5.5

in H-plane (yoz-plane). The antenna has stable radiations in both phi $= 0°$ plane (xoz-plane) and phi $= 90°$ plane (yoz-plane) across the whole operating band. The measured pattern results agree well with the simulated ones. At higher frequencies, the E-plane radiation patterns have a little distortion. Measured and simulated gains are shown in Fig. 9. The measured gain of the antenna is from 1.5 dBi (lower band) to 5.5 dBi (higher band).

Comparison of the proposed antenna with some antennas available in the references are shown in Table 2. In the table, ΦR stands for that the radius of the antenna is R, and Hb means that the height of the antenna is b. As shown in Table 2, the proposed antenna has larger bandwidth, smaller VSWR, and lower frequency than the existing antennas [1, 3–6]. The ground area of the proposed antenna is reduced more than 50% compared to the antennas in the references [1, 3–5] and 25% in [7], and because of the planer structure ($H = 2$ mm), the proposed antenna is much lower in height than all the antennas in the references. These advantages demonstrate the compactness and superiority of the proposed antenna.

4. CONCLUSION

A compact planar broadband slot antenna has been practically verified. In this design, the broadband property is improved by etching a polygon slot in the ground plane. At the lowest operating frequency, the antenna achieves small electrical dimension of $0.327\lambda \times 0.327\lambda \times 0.0046\lambda$. The proposed antenna has VSWRs lower than 1.5 across a frequency band of 0.66 to 3.07 GHz. Because of the compact dimensions and vertically-polarized omnidirectional radiation characteristics, the proposed antenna could be used as a good candidate for ceiling or surface mounted indoor distributed antenna system applications.

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