Low Profile High-gain Antenna for Broadband Indoor Distributed Antenna System

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Abstract **─** Here an improved folded patch antenna with low profile and high gain is proposed. By loading slow-wave metamaterials structure and metal pillars, the antenna operates from 0.6 GHz to 2.1 GHz (111% fractional bandwidth) with the VSWR<2. The profile height is 48.5 mm and 0.095λ at 0.6 GHz. The measured gain is 4 dBi at 0.6 GHz. The average gain is 7.43 dBi over the entire bandwidth. Hence, it is an excellent candidate for the emerging multiband indoor base station application such as 700 MHz, CDMA800, GSM900, DCS1800, PCS1900, UMTS, and IMT2000, etc.

Index Terms **─** 5G, broadband, folded patch, high gain, metamaterials.

I. INTRODUCTION

The demands for high speed and broadband data services for mobile users are growing dramatically and more than 80% mobile data traffic is originated in the indoor environments, for instance, commercial buildings and airports [1]. Thus, the indoor distributed antenna systems (IDAS) which are employed to provide wireless communication coverage in high-traffic indoor areas are becoming more and more important [2]. Since most of the antennas for IDAS are mounted on the ceilings or wall of indoor areas, they are required to have a low profile and a high gain [1]. Furthermore, more frequency bands have been commercially allocated for different communication systems to provide better communication services, such as 2nd generation (2G), 3G, 4G, and 5G. The most widely used 2G-5G frequency spectrum in the world today is 700, 800, 1800, 1900, 2100, and 2600 MHz. Recently, 700 MHz was allocated to China Broadcasting Network Corporation Ltd. (CBN). 700 MHz frequency will save the investment of 5G network deployment because it uses fewer sites because of its large-area network coverage. In addition, the 700 MHz frequency also offers good signal penetration in buildings, basements and elevators. Hence low-profile broadband antennas which can simultaneously cover multiple service bands are in great demand [1], especially those antennas covering 700 MHz.

The printed patch antenna is a good choice due to its low-profile feature, but it inherently suffers from the weakness of narrow bandwidth [3]. To improve the bandwidth for broadband applications, different kinds broadband printed antennas have been proposed, such as modified fractal antenna [4,5], planar elliptical antenna [6-8], notched trapezoidal monopole antenna [9], dual band-notched circular ring antenna [10], a half-disc and a half-ellipse antenna [11], and a back-to-back triangular shaped patch antenna [12]. However, the previous antennas suffer from low gain at low frequency, for example, the peak gain is ~ 0 dBi at 650 MHz for the antenna in [13] and the peak gain is 0 dBi at 1 GHz for the antenna in [14].

Since the antennas for IDAS are mounted on the ceilings or wall, there is always a big ground plane. To obtain high gain, the monopole or dipole antenna with a perpendicular ground plane is a good choice. However, such antennas suffer from high profile at low frequencies. A loop-loaded dipole antenna ranging from 880-2700 MHz [2], a low-profile sleeve monopole ranging from 750-2660 MHz [15], a dual-sleeve monopole antenna ranging from 730 to 3880 MHz [16] and a triple-band folded patch antenna with a shorting wall from 720 MHz [17] have been achieved. Their heights are 50 mm, 29 mm, 29 mm, and 39 mm, respectively. But all the above antennas cannot still cover 700 MHz. By incorporating a shorted coupling top loading structure over two cross-connected monopole antennas, an enhanced bandwidth ranging from 650 to 4500 MHz (152%) for a reflection coefficient <−15 dB is achieved. The achieved gain is 2 dBi for the 650-960 MHz band [3]. However, its profile height is 85 mm.

Wideband folded feed *L*-slot folded patch antenna ranging from 0.72 to 3.6 GHz was proposed and analyzed [18-20]. It has been shown that by loading slow-wave metamaterials structure, the miniaturization of the antennas can be realized [21-22]. Compared to the original antenna in Ref. [18], two metallic pillars are added onto the upper folded part to miniaturize the antenna and a slow-wave metamaterials structure is loaded to improve further the gain at higher frequency

Submitted On: December 31, 2019
Accepted On: May 13, 2020

band. The improved folded patch antenna with low profile and high gain ranging from 0.6 GHz to 2.1 GHz for VSWR < 2 has been fabricated. The gain is 4 dBi at 0.6 GHz. The average gain is 7.43 dBi over the entire bandwidth. Hence, it is an excellent candidate for the emerging multiband indoor base station application such as 700MHz, CDMA800, GSM900, DCS1800, PCS1900, UMTS, and IMT2000, etc.

II. ANTENNA DESIGN

Figure 1 shows the 3D perspective view and configuration of Antenna 1, which is mounted in the middle of a square ground plane with the dimensions of 290 mm × 290 mm. The patch antenna consists of a vertical wall shorted to the ground plane, a horizontal patch cut with an *L*-shaped slot, a vertical metallic wall, and the upper horizontal patch. The coaxial probe is used to excite the antenna which is connected to the lower folded part. First, in order to make the operating frequency shift to the lower frequency, two metallic pillars shown in Fig. 1 (a) are loaded to the upper folded patch. The detailed sizes are l_1 = 90 mm, l_2 = 113 mm, l_3 = 36 mm, l_4 = 16 mm, w_1 = 52 mm, w_2 = 55.5 mm, w_3 = 18 mm, w_4 = 31 mm, w_5 = 5 mm, h_1 = 18 mm, h_2 = 40 mm, h_3 = 2.5 mm, h_4 = 8.5 mm, and d_1 = 4 mm.

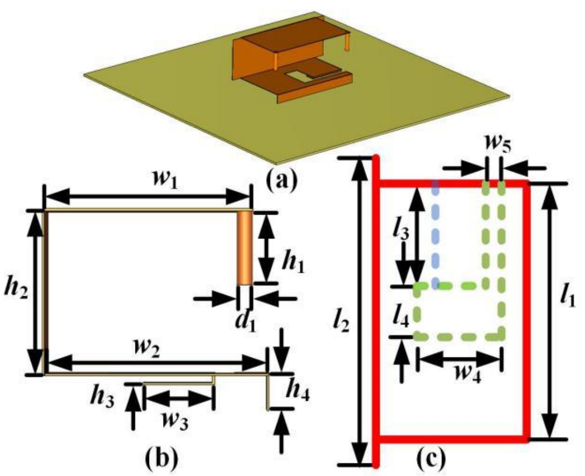

Fig. 1. (a) 3D perspective view, (b) side view, and (c) bottom view of Antenna 1.

To improve the gain at higher frequency band, a slow-wave metamaterials structure is loaded, which is shown in Fig. 2 and denoted by Antenna 2. The optimized parameters of the slow-wave structure are l_5 = 90 mm, w_6 = 6.5 mm, h_5 = 2.5 mm, and h_6 = 6 mm, respectively.

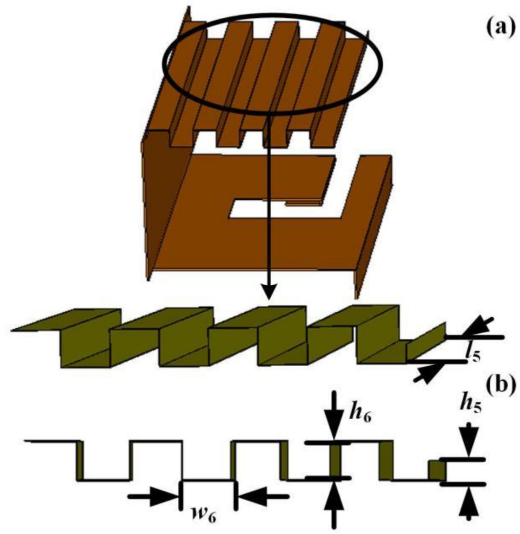

Fig. 2. (a) The structure of Antenna 2, and (b) the details of the slow-wave metamaterials structure.

III. RESULTS AND DISCUSSIONS

A. Simulated results

The reflection coefficients and VSWR of Antenna 1 are obtained by using the commercial software HFSS 15.0, which is based on finite element method (FEM). The results are shown in Fig. 3. It can be seen that the operating frequency of Antenna 1 is from 0.6 GHz to 2.1 GHz when S_{11} is lower than -10 dB or VSWR < 2. Hence, the relative impedance bandwidth reaches up to 111%. However, it can be seen that the gain decreases for Antenna 1 at higher frequency band (larger than 1.6 GHz). A slow-wave metamaterials structure is loaded to improve further the gain at higher frequency band.

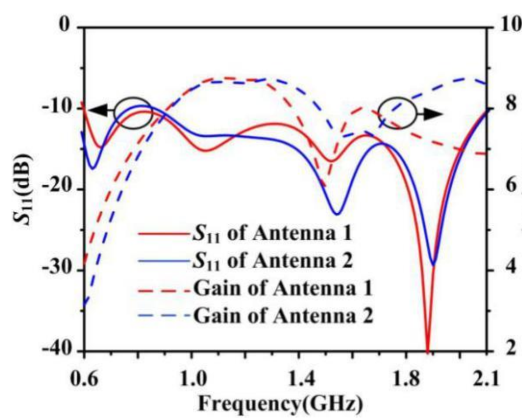

Fig. 3. Simulated reflection coefficients and gains of Antenna 1 and Antenna 2.

One unit cell of the slow-wave structure is used and the boundary conditions in the simulation are illustrated in Fig. 4 (a), where periodic boundary condition (PBC) is used in x direction and perfect electric conductor condition (PEC) is used in the other directions. The eigenmode solver of the commercial software CST microwave studio is adopted. From the dispersion curves shown in Fig. 4 (b), it can be seen that the dispersion curve is on the right side of the light line, which is the slow wave zone. The dispersion curve becomes lower when groove height h_6 increases. For the same operating frequency, the corresponding wave vector β would be larger for the lower dispersion curve.

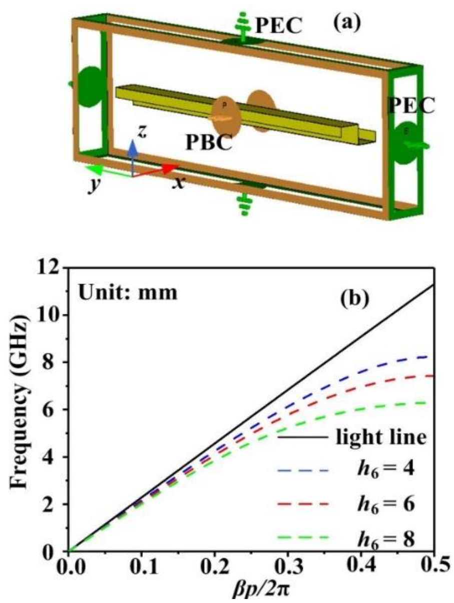

Fig. 4. (a) The boundary conditions in the numerical simulations, and (b) dispersion curves of the slow-wave structure.

B. Experimental results

The fabricated antenna (the material is aluminum) is shown in Fig. 5, whose thickness is 0.5 mm. The radiation pattern and gain measurements were conducted in the commercial chamber, whose minimum operating frequency is 600 MHz.

The measured reflection coefficients and gain are shown in Fig. 6. From Fig. 6 (a), it can be seen that the measurement results agree well with the simulation results. From Fig. 6 (b), we can see that the measured gain is a little lower than the simulation results. The measured average gain is 6.11 dBi over the entire bandwidth. It may be caused by the manual welding of the coaxial probe to the lower patch.

The simulated and measured radiation patterns at 1.1 GHz, 1.6GHz, and 2.1 GHz are shown in Fig. 7. It can be seen that the measured results agree well with the simulation results. Due to the asymmetry of the antenna structure, the radiation patterns are a little asymmetric. Finally, the performances of the proposed antenna are compared with other antennas in Table 1. Compared to the printed antenna, the proposed antenna has a high gain. It is 4 dBi at 0.6 GHz. Compared to the antennas [14-16, 18] from Table 1, the profile height is not more than 0.1λ and the operating frequency is ranging from 0.6 GHz to 2.1 GHz, covering the 700 MHz. Specially, the measured average gain is highest (7.43 dBi) over the entire bandwidth.

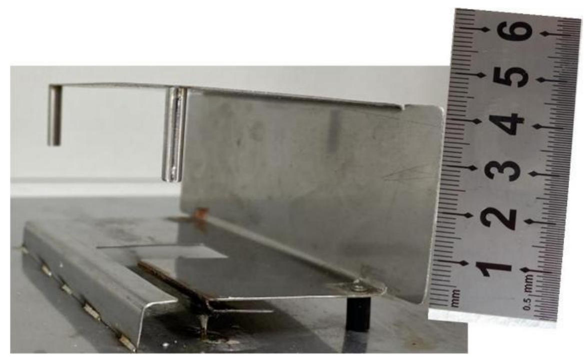

Fig. 5. The sample of the fabricated antenna.

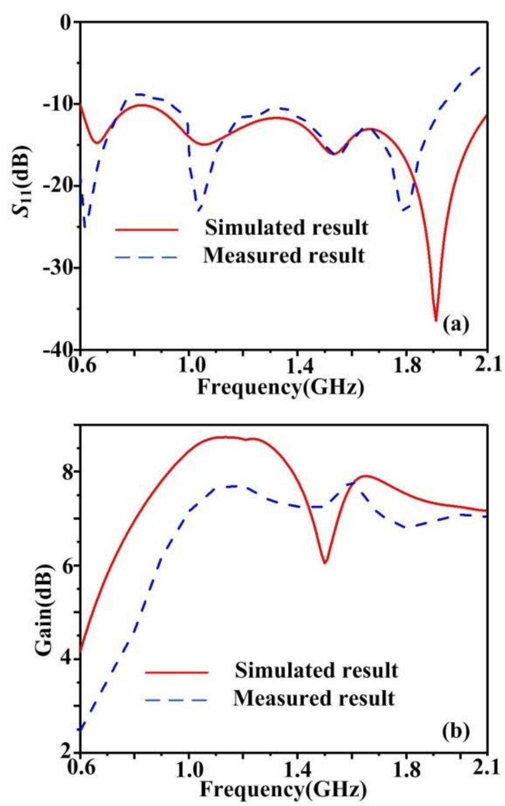

Fig. 6. Simulated and measured (a) reflection coefficients and (b) gain of Antenna 1.

Table 1: Comparison of the related researches

Antenna	Dimensions (mm)	Electrical Size (λ: Wavelength at the Lowest Frequency)	%	f_L (GHz)	Gain
[2]	120 × 120 × 50	0.352 λ × 0.352 λ × 0.15 λ	102	0.88	/
[3]	150 × 150 × 85	0.325 λ × 0.325 λ × 0.18 λ	161	0.65	1.9 dBi @ 1.7 GHz
[5]	19.2 × 14.4 ×1	0.032 λ × 0.024 λ × 0.0017 λ	193	0.5	2 dBi @ 2 GHz
[6]	15 × 29 × 0.787	0.032 λ × 0.063 λ × 0.0017 λ	168	0.65	~ 0 dBi @ 0.65 GHz
[8]	149 × 107.3 × 1.524	0.204 λ × 0.147 λ × 0.0021 λ	182	0.41	0.4 dBi @ 1 GHz
[12]	156.3 × 150 × 0.5	0.333 λ × 0.32 λ × 0.001 λ	185	0.64	4 dBi @ 2 GHz
[14]	97.8 × 136.9 × 1.524	0.15 λ × 0.21 λ × 0.0021 λ	170	0.46	~ 0 dBi @ 1 GHz
[15]	132 × 132 × 29	0.33 λ × 0.33 λ × 0.0725 λ	112	0.75	/
[16]	130 × 130 × 29	0.316 λ × 0.316 λ × 0.071 λ	137	0.73	2.5 dBi @ 0.75 GHz
[18]	56.2 × 113 × 33	0.135 λ × 0.271 λ × 0.079 λ	133	0.72	Average: 5.7dBi
Proposed antenna	55.5 × 113 × 48.5	0.109 λ × 0.222 λ × 0.095 λ	111	0.6	Average: 7.43dBi

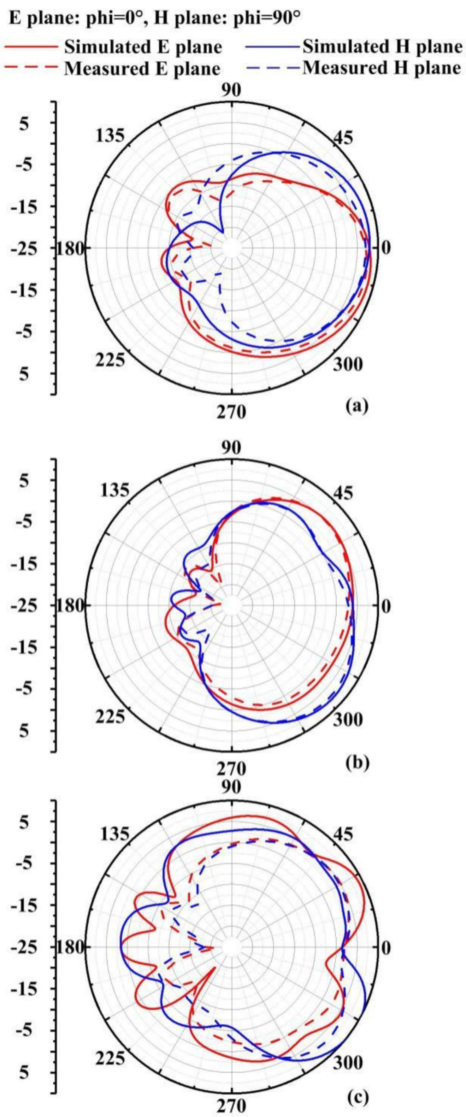

Fig. 7. Radiation patterns at: (a) 1.1 GHz, (b) 1.6 GHz, and (c) 2.1 GHz.

IV. CONCLUSION

By loading the slow-wave metamaterials structure and metal pillars, an improved low-profile high-gain folded patch antenna was demonstrated. The operating frequencies cover from 0.6 GHz to 2.1 GHz with the VSWR<2. Its profile height is only 0.095λ at 0.6 GHz. The measured gain is 4 dBi at 0.6 GHz. The average gain reaches up to 7.43 dBi over the entire bandwidth. The antenna is suitable for the emerging indoor base station applications such as 700MHz, CDMA800, GSM900, DCS1800, PCS1900, UMTS, and IMT2000, etc.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China under Grant No. 61971469, and by Science and Technology Commission Shanghai Municipality (STCSM) under Grants No. 18ZR1413500 and SKLSFO2017-05.

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