A Wideband Omnidirectional Printed Array Antenna

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Abstract—This letter presents an omnidirectional printed dipole antenna array with a wide bandwidth. The array is composed of four dipole units etched on a thin substrate, which is simple in structure and easy to be processed. By modifying the triangle-shaped radiation dipole units and gradually increasing the width of microstrip feeding transmission line, the performance of the dipole antenna array is greatly improved. Simulation results show that this omnidirectional antenna has a peak gain greater than 7.39 dBi, and the impedance bandwidth is 16% (VSWR < 1.6), ranging from 2.3 to 2.7 GHz.

1. INTRODUCTION

In radio communication, an omnidirectional antenna is a class of antennas which radiate radio wave power uniformly in all directions in one plane, with radiated power decreasing with elevation angle above or below the plane, dropping to zero on the antenna's axis. This makes omnidirectional antennas widely applied in wireless communication systems. For example, in order to enable high-speed mobile platforms with indefinite moving trajectories like vehicles, airborne and shipboard and base stations to receive electromagnetic waves in various states, their antennas are generally required to have good omnidirectional radiation characteristics. Therefore, the study of omnidirectional antennas is of great practical significance and engineering value.

Recently, a variety of omnidirectional printed array antennas have been put forward. The typical omnidirectional printed antenna is a dipole antenna which has two identical rectangular arms on each side of the substrate. In [1] the dipole printed antenna has a gain greater than 5.0 dBi, but its relative bandwidth is only 5%. A coupling-fed omnidirectional printed dipole antenna with radiated loads is reported in [2, 3], whose impedance bandwidth can reach 16% ($S_{11} < -10$ dB), and the maximum gain exceeds 5.0 dBi. A triband shunt-fed omnidirectional planar dipole array is introduced in [4], and this antenna can work at bands of GSM850 (824–894 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) and can reach a gain greater than 3.8 dBi. Reference [5] reports an omnidirectional printed dipole sleeve antenna array that has a bandwidth of 36% for $S_{11} < -10$ dB, and the gain is greater than 4.7 dBi. Although the metal shielding sleeve can help the array to achieve a wider bandwidth, it has high processing cost and big size. There are some other kinds of printed omnidirectional antennas, like planar slot array antenna and COCO antenna. A novel planar slot array antenna with omnidirectional pattern has been presented in [6], and its measured gain reaches 10 dBi, but the measured impedance bandwidth is too narrow (4.6% for $S_{11} < -10$ dB). Reference [7] presents an omnidirectional printed collinear microstrip antenna array, which works at $1 \sim 1.15$ GHz with a bandwidth of 14% for VSWR ≤ 1.5 and corresponding gain of 6 dBi.

By winding and notching on the typical printed dipole radiation arms, the size of printed elements can be reduced, and the antenna can get better performance [8]. In this letter, an improved omnidirectional printed dipole wideband array antenna is proposed, fabricated, and measured. To broaden the bandwidth and improve the impedance characteristics, the structure of dipole array antenna

is optimized. Compared to other printed dipole array antennas, this array antenna is low in VSWR and has excellent performance on the omnidirectional radiation patterns, and the measured gain is stable in the operating band.

2. ARRAY ANTENNA DESIGN

2.1. Array Antenna Structure

The structure of the proposed omnidirectional printed array antenna is shown in Fig. 1. The array antenna is printed on a layer Neltec NY9220 (IM) substrate with the relative permittivity of 2.2 and loss tangent of 0.0009. The geometrical parameters of the antenna array are given by Table 1. It contains three parts, including radiation elements, gradient microstrip transmission line and feeding.
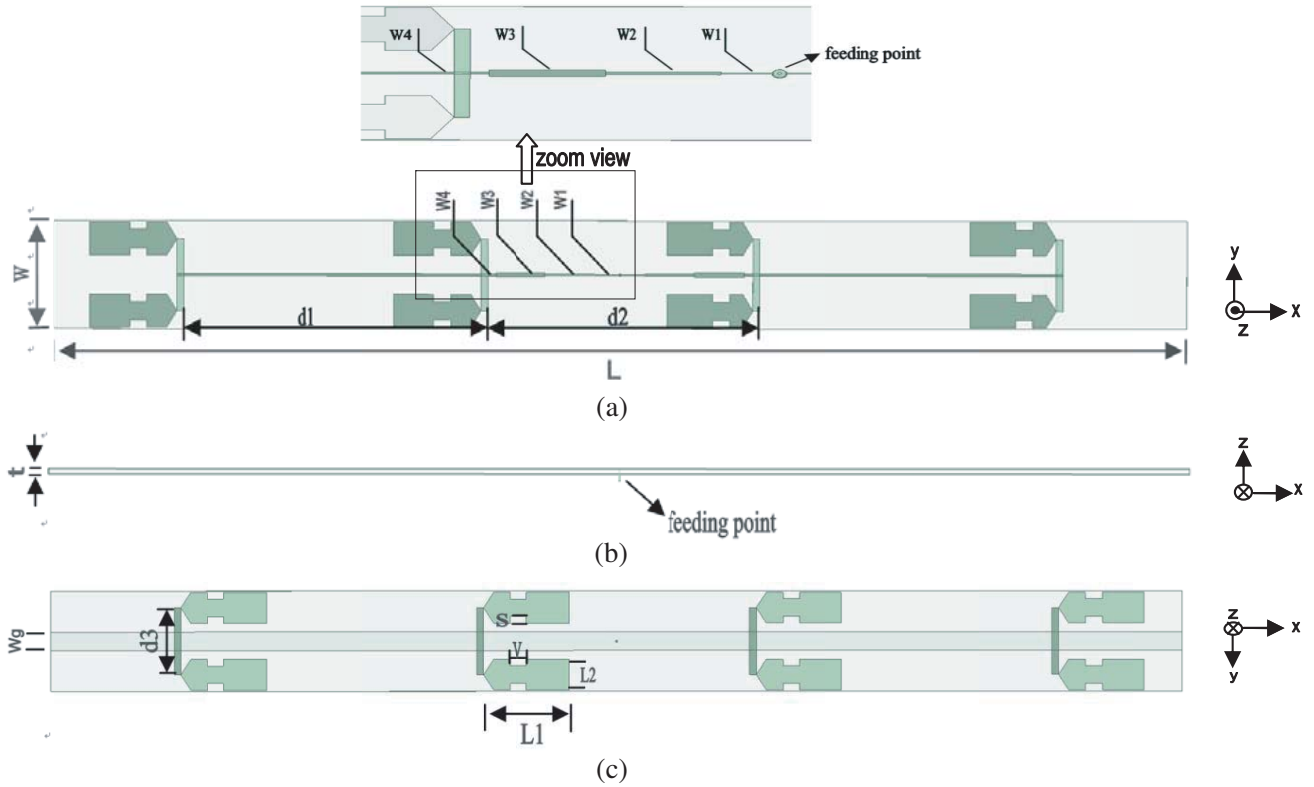
Figure 1. Geometry of the proposed antenna array. (a) Top view. (b) Side view. (c) Bottom view.

**Table 1.** Geometric parameters of the proposed antenna array.

W	30 mm	$d1$	91 mm
L	340 mm	$d2$	82 mm
t	1.52 mm	$d3$	20 mm
$W1$	0.2 mm	$L1$	25.9 mm
$W2$	0.4 mm	$L2$	9.2 mm
$W3$	1.2 mm	s	2 mm
$W4$	0.6 mm	v	5 mm
Wg	5.5 mm		

The basic array radiation element is printed dipoles that are symmetrically arranged on both sides of substrate, as shown in Figs. 1(a) and (c). In this structure, the dipole arm has a wide width of $L2$, which can help to widen the working bandwidth effectively. The total dipole length ($2L1$) is approximately designed to be 50% of one wavelength λ_g, where λ_g is the center frequency's wave length in dielectric, i.e., each printed dipole arm has a length $L1 \approx \lambda_g/4$. Two rectangular slots are cut into each unit, in order to produce electrically shorter elements that extend the bandwidth and improve impedance characteristics. There are four pairs of the basic printed dipoles elements along the cuboid substrate constituting the omnidirectional antenna array in all. The transverse spacing of the printed dipoles is $d3$, and the longitudinal spacing is $d1$, $d2$ respectively. Moreover, tapered configuration is used in the feeding end of radiation elements to improve the impedance characteristics at the input end and widen the working bandwidth effectively.

As shown in Fig. 1(a), a microstrip transmission line consists of four sections. In order to match the coaxial line with a characteristic impedance of $50\,\Omega$ to the input terminal of the printed dipoles radiation part, four kinds of microstrip transmission lines with different characteristic impedances and electrical lengths are devised on the basis of the theory of transmission line. The widths of the microstrip lines are $w1$, $w2$, $w3$, and $w4$, respectively. The corporate-fed method is used to feed Ω in the middle of the array antenna. Moreover, a long narrow microstrip line is arranged in the middle of the back surface of the substrate, and the width is Wg, whose function is to match the four $50\,\Omega$ microstrip transmission lines in the front surface of the substrate.

2.2. Design Principle

Omnidirectional antenna has many structures, but a high-gain omnidirectional antenna is mostly an erect collinear array structure and is usually achieved by using resonant units to form an array like Franklin omnidirectional collinear antenna array, collinear folded antenna array, coaxial collinear antenna, etc. [9]. In this letter, the array still chooses a vertical collinear array structure. Since undesired upturn is usually observed in radiation pattern when bottom feeding is adopted, the feeding point of the proposed antenna is located in the middle of the array. Fig. 2 shows the array element arrangement. The longitudinal antenna 1#, antenna 2#, antenna 3#, antenna 4# and antenna 5#, antenna 6#, antenna 7#, antenna 8# can be regarded as a combination unit respectively [10]. The radiation directions of the two combinational units are the same, and the radiation pattern of each combinational unit is a circle in the horizontal plane [10].
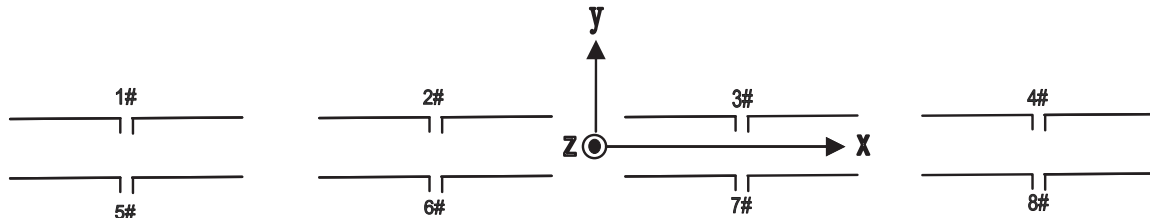
**Figure 2.** The arrangement of the proposed antenna array.

Based on the principle of collinear array, the total field intensity of the whole antenna array can be calculated as [9]:

$$E = E_0 \left[1 + e^{j\psi} + e^{j2\psi} + \ldots + e^{j(n-1)\psi} \right]$$
$$= E_0 e^{j\frac{n-1}{2}\psi} \cdot \frac{\sin\frac{n\psi}{2}}{\sin\frac{\psi}{2}} \tag{1}$$

Among them, $n = 4$, $\psi = ad\cos\varphi$. When $\varphi = \pm 90°$, it is the maximum radiation direction of pattern. By way of guaranteeing the waves radiated from each unit of the dipole array with the equal phases, the array elements should be at an interval of λ_g one wavelength of the center operating frequency [9].

Through simulation test and optimization, we finally find that the array has an excellent property at a distance of $d1 \approx 1.12\lambda_g$ and $d2 \approx \lambda_g$.

Slotting on the patch can change the current distribution on the antenna and reduce the antenna radiation impedance, thereby effectively improving antenna impedance matching and widening the bandwidth of the antenna. Thus two rectangular slots are cut into each element, in order to produce better impedance characteristics. To verify the effect of the slots, we simulate and test the array using Ansoft simulation software HFSS 17.0. As shown in Fig. 3, the introduction of rectangular slots greatly improves the VSWR in the operating bandwidth.
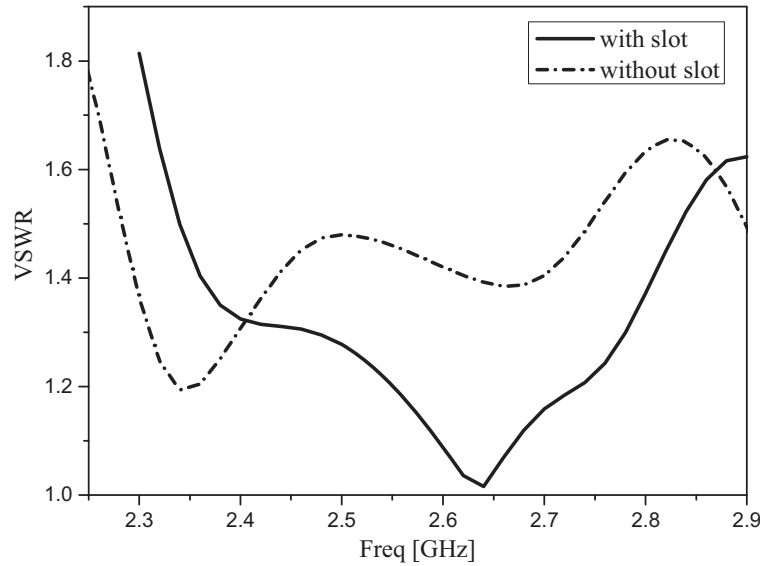
**Figure 3.** VSWR in comparison of the slotted and nonslotted antenna array.

(a)   (b)
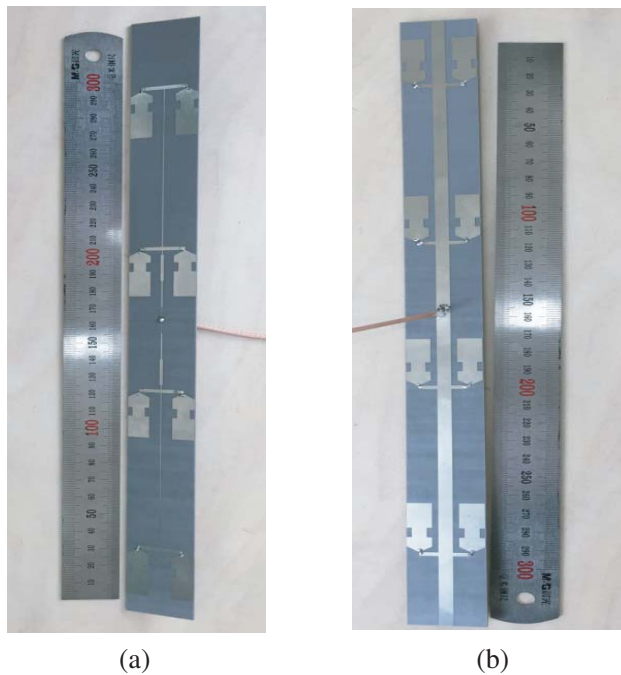
**Figure 4.** Photograph of the designed antenna array. (a) Front side. (b) Back side.

3. RESULTS AND DISCUSSION

This part will present the simulated and tested results of the proposed antenna array. Fig. 4 presents the image of the final fabricated omnidirectional printed antenna array.

The results of simulated and measured VSWRs are presented in Fig. 5. It is found that the measured impedance bandwidth of VSWR < 1.6 is 16% ranging from 2.3 to 2.7 GHz, and the VSWR < 2 even covers 1.74 GHz ~ 2.70 GHz, realizing a relative bandwidth of 45%. The measured result of VSWR shows good agreement with the simulated one but is slightly higher. It may be because of the coaxial feed line in the real antenna, which brings more loss and reflection than the lumped port in simulation. Fig. 5(b) shows that the radiation efficiency of the antenna array is more than 97% over the designed operating band. Figs. 7(a)–(c) show the simulated and measured E-plane (yz-plane) and H-plane (xy-plane) radiation patterns at 2.3, 2.5, and 2.7 GHz, respectively. Good agreement is achieved between the simulated and measured results. Moreover, the H-plane has basically omnidirectional radiation in the whole frequency band, and the gain variation in the azimuth plane is less than 2.4 dBi. The gain of the antenna in the whole frequency band is as shown in Fig. 6, and the measured result is in good
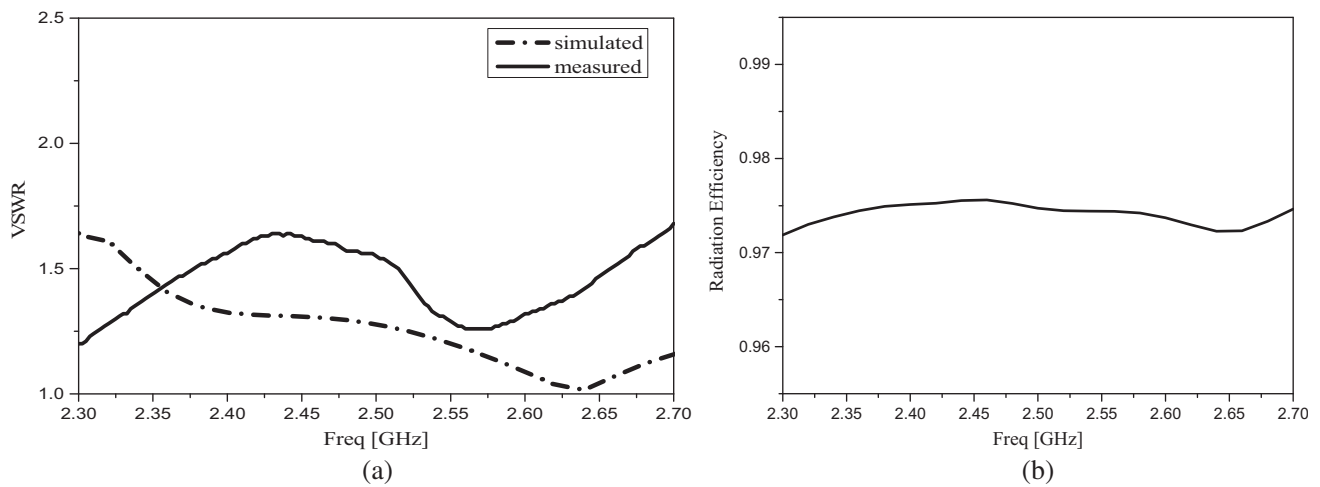
Figure 5. Simulated and measured results of the array. (a) VSWR. (b) Radiation efficiency.
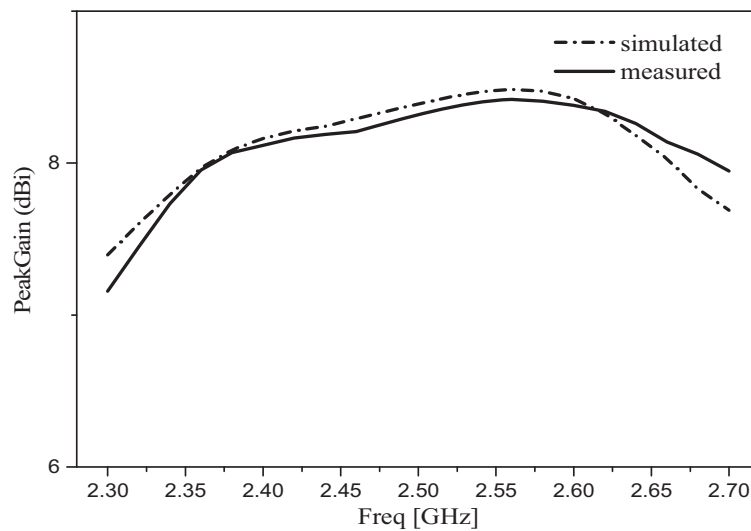
Figure 6. Simulated and measured gain of the array.
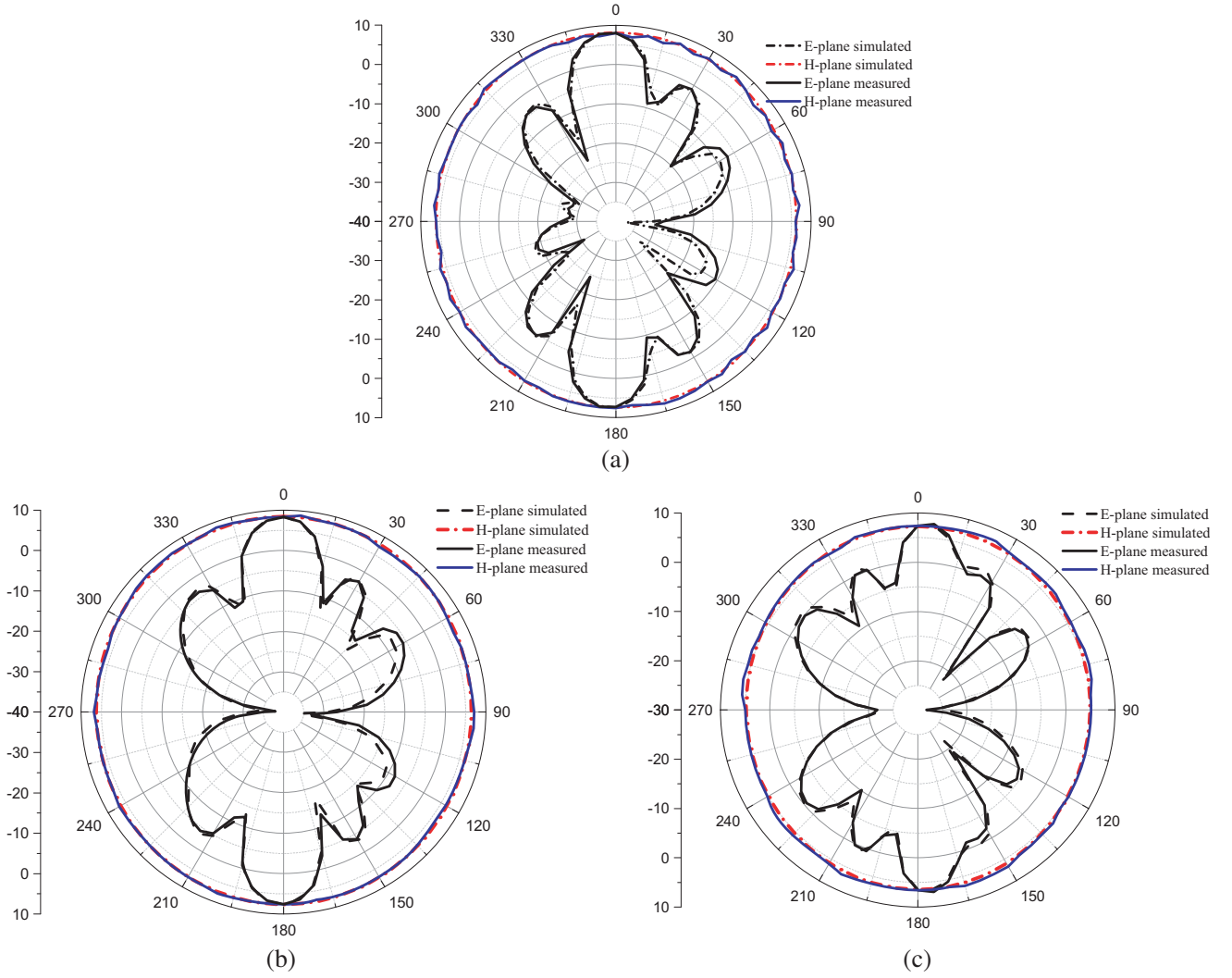
Figure 7. Simulated radiation pattern at xz-plane and yz-plane. (a) 2.3 GHz. (b) 2.5 GHz. (c) 2.7 GHz.

Table 2. Comparison between the proposed antenna array and other antennas.

Antenna Type	Operating Bandwidth	Relative Bandwidth	Maximum Gain	Antenna Size
The Proposed Antenna	2.3 to 2.7 GHz (VSWR < 1.6)	16% (VSWR < 1.6)	8.48 dBi	340 mm × 30 mm × 1.52 mm
The Antenna in [1]	2.4 to 2.484 GHz (VSWR < 1.5)	5% (VSWR < 1.5)	6.1 dBi	176 mm × 18 mm × 0.4 mm
The Antenna in [2]	4.65 to 5.61 GHz (VSWR < 2)	18.7% (VSWR < 2)	5.4 dBi	102 mm × 29.8 mm × 1.5 mm
The Antenna in [3]	4.63 to 5.45 GHz (VSWR < 2)	16.3% (VSWR < 2)	5.8 dBi	113 mm × 12.6 mm × 1.5 mm
The Antenna in [7]	1 to 1.15 GHz (VSWR < 1.5)	14% (VSWR < 1.5)	6 dBi	770.6 mm × 19 mm × 1.6 mm

agreement with simulated one. The measured maximum gain is 8.42 dBi, and the minimum gain is 7.39 dBi. As we can see from the experimental results, the gain of the designed dipole antenna array is very stable in the working bandwidth. At last, we compare the proposed antenna array with those in other inferences as illustrated in Table 2. It demonstrates that the bandwidth and gain of the proposed antenna are the highest among all antennas.

4. CONCLUSION

An omnidirectional wide band printed dipole antenna array with stable gain is designed, and the results display a good performance in impedance bandwidth, stability of gain and omnidirectivity. As shown in the result of measurement, it has a wide bandwidth of VSWR < 1.6 ranging from 2.3 to 2.7 GHz with a gain higher than 7.39 dBi. Besides, its gain variation is less than 2.4 dBi in the H-plane. At the same time, as the proposed antenna array has a thin and light weight structure, it has excellent advantage to apply in the modern communication systems of 3G-4G. Moreover, it is easy to increase the number of the basic radiation elements to adjust the array gain for wider application.

ACKNOWLEDGMENT

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