High-Gain Omnidirectional Horizontally Polarized Dipole Array for Sub-6 Base Station

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***Abstract*—A novel omnidirectional horizontally polarized dipole antenna array with wide bandwidth and high gain is reported, which operates at sub-6 band. A major improvement is the feeding method for omnidirectional radiation patterns which is inspired by classic turnstile antenna array. Six pairs of modified cross dipoles are positioned along a parallel feeding wire transmission line, and the dipole elements are placed in two orthogonal planes, with six dipole elements in each plane. The adjacent dipole elements on different planes are spaced by a quarter wavelength to produce an omnidirectional radiation pattern. The antenna array is simply machined with 1 mm diameter copper wire and fed by a coaxial structure at the center of the array. The max cross section area is 3.17 × 0.5$\lambda_0{}^2$ which can be limited in a cylinder. The measured and simulated results are in good agreement. The measured –10 dB impedance bandwidth covers 1.19 GHz from 3.83 to 5.02 GHz and the measured peak realized gain value is 7.44 dBi. The measured 1 dB gain bandwidth of the proposed antenna is 1 GHz (22%) from 4 to 5 GHz. The advantages of high gain, broadband, omnidirectional radiation, and low cost make this antenna favorable in base station situations.**

***Index Terms*—Horizontally polarized (HP) dipole array, omnidirectional patterns, series-fed antenna array, sub-6 band.**

I. Introduction

OMNIDIRECTIONAL antennas are popular applications in wireless communications where full coverage of the surrounding environment is required, such as TV broadcasting, base stations, and indoor wireless local area network (WLAN) [1], [2], [3], [4]. In beyond 5G communication systems, the centralized radio access network (C-RAN) has been devised to enable stable, high-quality, and high-capacity communication irrespective of the user's location. By increasing the number of base stations per area and reducing the service area of one base station, C-RAN creates a communication-friendly environment even in crowded areas. Compact omnidirectional antennas are easy to implement in this case, with sufficient coverage and low cost compared to beamforming in the sub-6 band [5]. Usually, vertically polarized omnidirectional antennas are more easily achieved by monopole antennas, biconical antennas, or other forms [6], [7], [8], [9]. Because of the desire for polarization diversity, the researches of omnidirectional horizontally polarized (OHP) antenna become popular. Due to the nonexistence of magnetic dipoles (MDs), horizontally polarized (HP) omnidirectional antennas need array antennas such as cylindrical slit array antennas, cylindrical microstrip array antennas, turnstile antennas, and Alford loops [10], [11], [12], [13] to generate HP wave. To increase the bandwidth, parasitic elements can be used. It still remains an unsolved problem that the peak gain of those antennas is less than 4 dBi. If taking the average gain into account, the value will be less even more.

In communication engineering, the gain of the base station antenna must be required as high enough to cover a wide range, but there have been only limited researches on this. Part of the researchers has utilized a couple of designed HP antennas to establish antenna arrays to earn higher gain. In [14], a broadband HP omnidirectional planar antenna using arc dipoles is developed for mobile communications with peak gain of 8 dBi. However, the size of the antenna is larger than 7λ, and quite a number of feeding cables are needed, which makes the system more complicated and bulky. The traveling wave antenna has also been used for high-gain OHP radiation [15], but its beam changes at different frequencies. There are also some researchers that apply the idea of MDs to realize HP [16], [17]. In [17], the inverters are introduced into the substrate integrated waveguide (SIW) so as to obtain in-phase MDs. The total length of this antenna is 4.3λ, and the gain is about 10.4 dBi. However, for the SIW structure, excessive metal vias require high machining accuracy. A slender Fabry–Perot antenna is proposed for high-gain HP omnidirectional radiation in [18], and the 10 dB impedance bandwidth is achieved from 2.41 to 2.5 GHz with realized gain of 8.52 dBi. Although the antenna in [18] is prototyped with a desired compact size of 2.95λ, narrow bandwidth (about 3.7%) shows its most obvious drawback.

In this letter, a high-gain, broadband OHP dipole antenna array working at sub-6 band is introduced. The proposed array consists of several half-wavelength dipole elements set up in a parallel feeder wire transmission line. Six pairs of modified crossed dipoles are placed in two orthogonal planes, with six dipole elements in each plane. The distance between each dipole in the same plane, as depicted in Fig. 1(b), is half a wavelength. The adjacent dipole elements on different planes must be spaced by a quarter wavelength to produce an omnidirectional radiation pattern. The antenna array is made of 1 mm diameter copper wire and is fed by a coaxial structure in the middle of the array.

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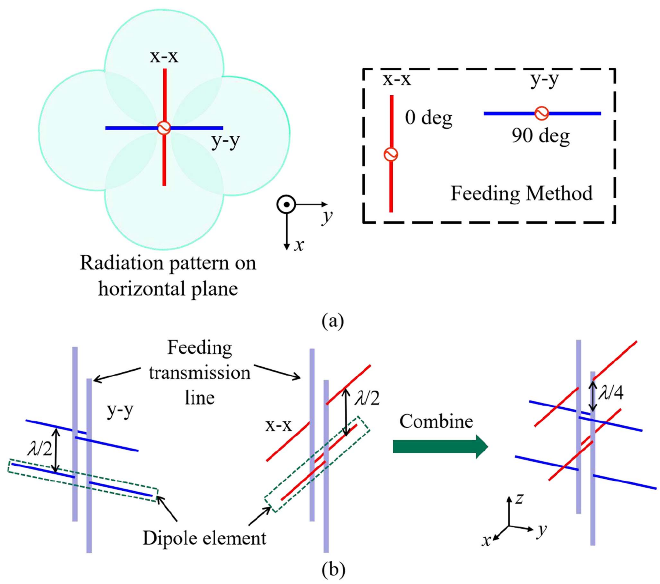

Fig. 1. Antenna configuration for omnidirectional pattern. (a) Radiation pattern and feeding method of turnstile antenna. (b) Configuration of proposed antenna array.

The results of the proposed antenna array agree well between simulation and measurement. The impedance bandwidth covers 1.7 GHz from 3.83 to 5 GHz. Furthermore, a measured maximum peak RG value of 7.44 dBi is achieved from 4 to 5 GHz. The design concept produces high-performance OHP arrays that are excellent candidates for a variety of wireless applications, such as WLAN base station antennas, and dense base station deployment scenarios.

II. Antenna Design and Methodology

One of the cornerstones of our design is how the dipole elements are organized. There are two concerns that should be addressed in relation to the series-fed antenna array. The first is meeting the maximum gain with broadside radiation. Instead of broadside, there have been numerous studies on endfire broadband series-fed dipole arrays [19], [20], [21], [22], [23]. The second is the implementation of turnstile feed in series-fed arrays, and there is hardly any pertinent study.

The current on each element of the planar array antenna must be the same in amplitude and phase to achieve maximum radiation. By designing the size of each individual element in turn, the series-fed antenna array's equal amplitude is obtained. According to the transmission line theory, an element must maintain a wavelength distance on the transmission line in order to maintain the same phase. However, undesirable overhead radiation will be visible. To meet the needs of in-phase and reduced overhead radiation at the same time, dipoles in the same plane are arranged half wavelength apart on the transmission line, and the two arms of neighboring dipole elements are rotated 180° in a shape similar to a log-periodic antenna, which may offer a 180° phase. In this approach, the electrical length of one wavelength conversion is achieved in the transmission line, while the adjacent dipole elements are spatially spaced half a wavelength away, effectively reducing the length of the array as well.

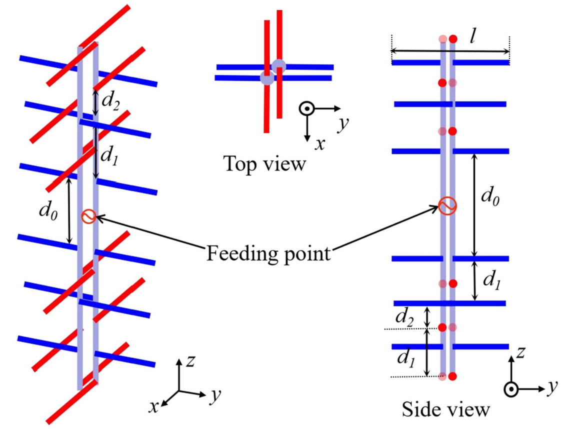

Fig. 2. Configuration of the omnidirectional series-fed dipole array.

The feeding method for omnidirectional radiation pattern was inspired by classic turnstile antenna, which is wildly used in Japan for broadcast transmitters at VHF and UHF bands [24], [25], [26]. As seen in Fig. 1(a), a pair of crossed dipoles are set up and fed by identical amplitudes and a 90° phase difference. The radiation pattern will be similar to that of two superimposed dipoles with a four-leaf clover shape to provide omnidirectional coverage. Traditional turnstile antennas use numerous feeding ports [15] or change the length of crossed dipoles [16] to create a 90° phase difference, which makes the antenna structure large or narrowband. As indicated in Fig 1(b), the previously proposed planar dipole array is proposed to rotate by 90°. They are dispersed in the *yoz* and *xoz* planes, respectively, and a quarter wavelength apart integrated on the same transmission line. An omnidirectional radiation pattern is produced as a result of the 90° phase difference that develops between two nearby dipole elements. The entire array can be thought of as six pairs of crossed dipoles spaced at half wavelength, with the dipole elements of each pair separated by a quarter wavelength. Fig. 2 illustrates the structure. It should be noted that misalignment of the crossed dipoles would distort the radiation pattern, however, this can be rectified by increasing the number of dipole elements.

III. Omnidirectional Horizontally Polarized Dipole Array

The proposed OHP dipole array is investigated to understand the operating principles and to evaluate its characteristics. High-frequency structure simulator (HFSS) is used to examine the antenna array. The fabrication of a linear antenna array is fairly simple. A parallel transmission line links each component to the others. The 1 mm copper wire is used to create a prototype. The measured and simulated results agree fairly well.

A. Antenna Configuration

As seen in Fig. 2, the proposed OHP dipole array is a symmetrical design. The 6 pairs of crossed dipoles are made up of 12 half-wavelength dipole elements dispersed on the *yoz* and *xoz* planes (here 4 GHz is chosen as the design frequency). The distance d_1 between consecutive dipole elements in the same

TABLE I
12-ELEMENT CENTER-FED OSFDA PARAMETERS

Parameter	Description	Value (mm)
l	Length of dipole element	37.5
d_0	Distance between center elements	50
d_1	Distance between elements in same plane	37.5
d_2	Distance between elements in different plane	18.75

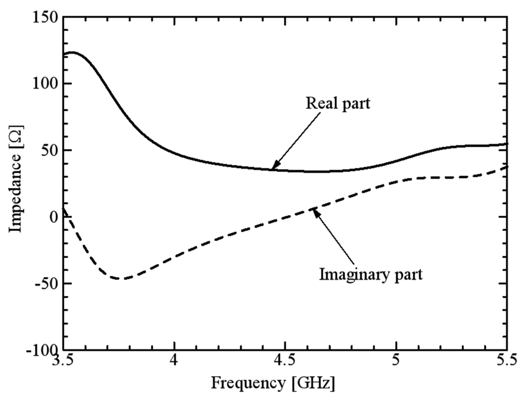

Fig. 3. Impedance of the OHP dipole array.

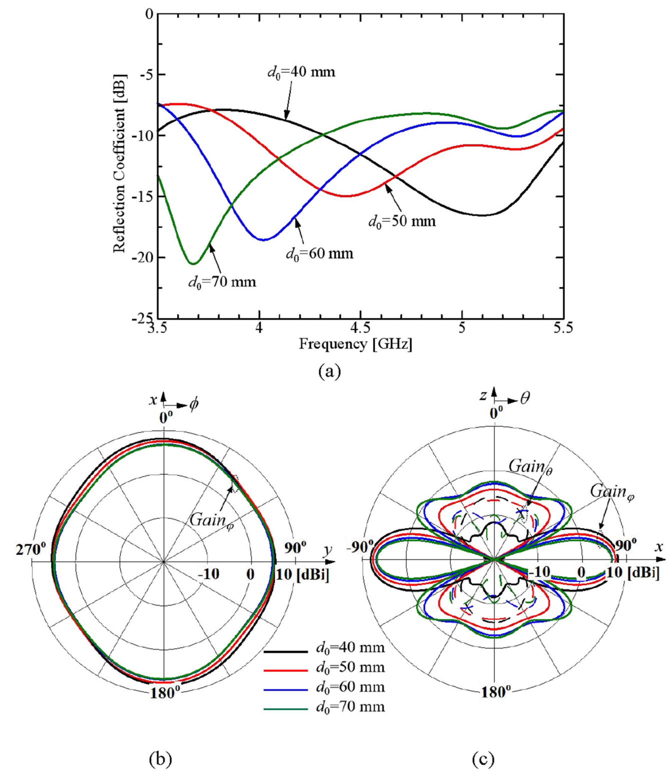

Fig. 4. Simulated results for different distance d_0. (a) Reflection coefficients. (b) Radiation patterns in horizontal plane (*xoy* plane) at 4.5 GHz. (c) Radiation patterns on vertical plane (*yoz*-plane) at 4.5 GHz.

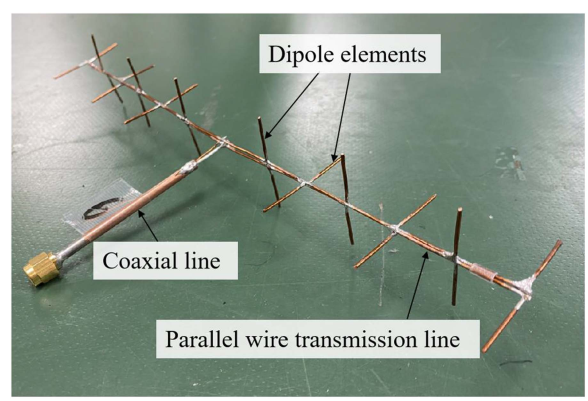

Fig. 5. Fabricated photograph of the six pair of modified cross-dipole elements OHP dipole array.

plane is a half wavelength, and the arms are rotated 180°. To achieve a phase difference of 90° between neighboring dipole elements in the orthogonal planes, the distance d_2 between them is set at a quarter wavelength. The detailed parameters are given in Table I.

B. Impedance Matching

In a simulation, the OHP dipole array is fed by the ideal port as illustrated in Fig. 3, the input impedance is determined. After 4 GHz, the real part of the antenna impedance flattens out and gets close to 50 Ω. While the imaginary portion of the antenna's input impedance gradually increases and goes through zero at 4.5 GHz, it presents that the antenna can achieve a relatively broadband matching with 50 Ω system near 4.5 GHz.

It is worth noting that the spacing between the dipole elements closest to the feed position has a significant effect on the impedance matching of the OHP dipole array. These results are summarized in Fig. 4(a) when d_0 increases from 40 to 70 mm. As d_0 increases, the size of the antenna increases, and the operating frequency shifts to low frequency band. The impedance bandwidth varies slightly but remains above 1 GHz. The radiation pattern is also influenced by d_0. Fig. 4(b) depicts the radiation pattern on a horizontal plane. For varied d_0, the radiation mostly retains a four-leaf clover shape, but the maximum gain changes slightly. Furthermore, the sidelobe and overhead radiation in the vertical plane, as illustrated in Fig. 4(c), rise as d_0 increases.

The design process to obtain an OHP dipole array operating at an arbitrary frequency is as follows. The fixed dipole element length is chosen as half wavelength. The actual impedance matching situation can be adjusted by d_0. An excessively large d_0 leads to excessive sidelobe and overhead radiation and needs to be avoided. In this letter, the OHP dipole array is designed for sub-6 frequency band so that $d_0 = 50$ mm is selected.

C. Fabricated Prototype and Measured Results

The fabricated prototype of the proposed OHP dipole array is shown in Fig. 5. The parallel transmission line and the dipole elements are made of 1 mm diameter copper wire and are welded to connect with each other. A coaxial line is used to excite the array, instead of matching circuit. The antenna is lightweight, easy to manufacture, and compact. A two-port VNA (Anritsu MS46122B) is used in the experimental setup to evaluate the

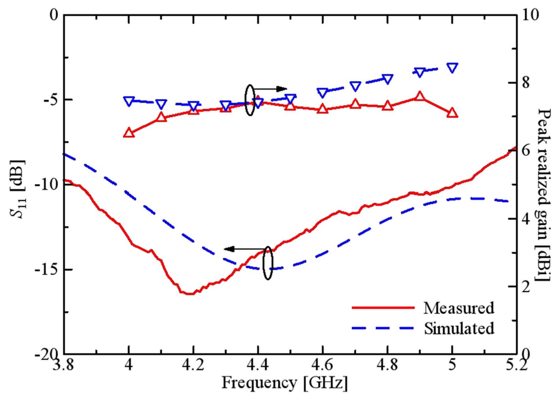

Fig. 6. Measured and simulated reflection coefficients and peak realized gain.

TABLE II
PERFORMANCE COMPARISON OF HIGH-GAIN OHP ANTENNA ARRAYS

Ref.	Frequency (GHz)	BW (%)	Max cross-secti on area (λ^2)	Peak realized gain (dBi)	RG per unit length (dBi/λ)
[14], 2012	1.67-2.27	34	7.11×1.11	8	1.13
[16], 2018	2.35-2.55	7.3	6×0.23	9.7	1.61
[17], 2020	9.6-10.4	8	4.3×0.22	10.4	2.42
[18], 2021	2.41-2.5	3.7	2.95×0.31	8.52	2.89
This letter	4-5	22	3.17×0.5	7.6	2.4

OHP dipole array. A turntable is applied to support the intended antenna. The VNA is put in an electromagnetic anechoic chamber covered with absorbing material to lessen cable losses.

The measured and simulated S_{11} and peak RG of the OHP dipole array are presented in Fig. 6. It can be observed that both results are in good agreement. Compared to the simulated results, the measured results shift to lower frequencies, but the trend is generally the same. The measured –10 dB impedance bandwidth is from 3.83 to 5.02 GHz, giving a relative impedance bandwidth of 26.89%. We were only able to measure the gain from 4 to 5GHz due to the frequency restriction of the tested receiver horn antenna. The simulation and measured peak RG agree well. The measured maximum peak RG value is 7.44 dBi at 4.4 GHz. In 4–5 GHz, the maximum gain difference is 1.38 dB, whereas 4.2–4.5 GHz is nearly the same. The peak RG of the proposed antenna fluctuates within 1 dB in the test band, and its gain bandwidth is about 22%.

The normalized RG patterns of the proposed antenna in the horizontal plane are shown in Fig. 7. The measured and simulated results agree well with each other. In the measured results, it is possible to see the distortion of the radiation pattern and the angle shift of the highest gain. The antenna is made of 1 mm diameter copper wire, which is thin and prone to deformation, so the modified crossed dipole elements cannot always be kept in their proper positions. This should be primarily the result of errors in the hand-made model.

Table II gives the results for the proposed OHP dipole array with the results of previous works. Some necessary parameters and information related are given for the purposes of a clear

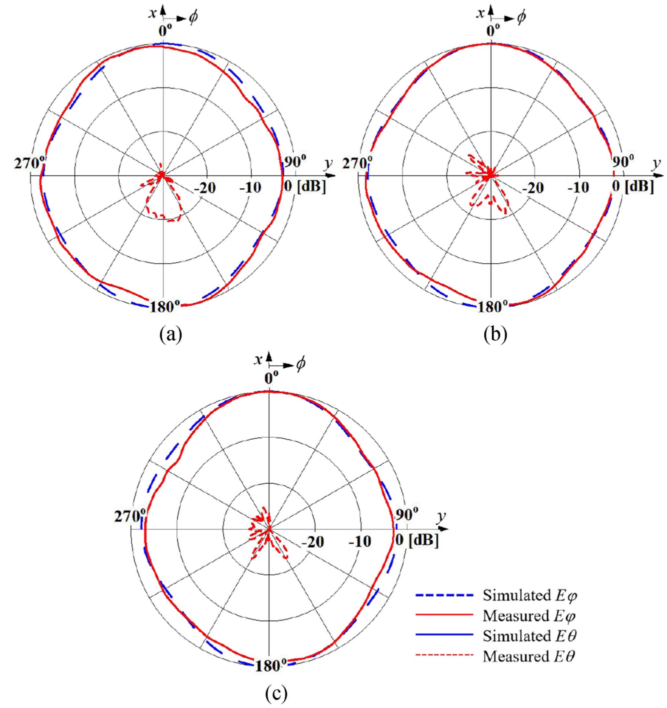

Fig. 7. Measured and simulated normalized radiation patterns of OHP dipole array in horizontal plane. (a) 4.3 GHz. (b) 4.5 GHz. (c) 4.7 GHz.

comparison, including operating frequency, size, peak RG, as well as RG per unit length. With the same gain level, the attained 22% bandwidth, for example, is significantly higher than the 7.3%, 8%, and 3.7% bandwidths in [11], [12], and [13], respectively. The design in [9] achieves a comparable bandwidth, 34%, although the structure is substantially longer. The RG per unit length (1.13 dBi) is substantially lower than our developed designs (2.4 dBi).

IV. CONCLUSION

In this letter, a novel high-gain OHP dipole array operating at sub-6 band with high gain was reported. The prototype was fabricated with 1 mm diameter copper wire and was excited by a coaxial line. The measured –10 dB impedance bandwidth was from 3.83 to 5.02 GHz giving a relative impedance bandwidth of 26.89%. The maximum peak realized gain reached 7.44 dBi at 4.4 GHz. The measured radiation patterns were in good agreement with the simulated ones. The simulated 1 dB gain bandwidth of the proposed antenna is 1 GHz (22%) from 4 to 5 GHz. The proposed antenna was outstanding in impedance bandwidth and realized gain. Therefore, it is ideal for base station with high gain horizontal polarization comprehensive coverage. And because of the low cost and ease of production, there are more options for multiple base station setups.

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