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A Novel Feeding Method for Broadband Series-fed Omnidirectional Antennas

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Abstract　This paper presents a novel omnidirectional horizontally polarized (OHP) dipole antenna array with broadband designed for the Sub-6 GHz band. Inspired by the feeding method of turnstile antenna, the omnidirectional radiation of the series-fed antenna is achieved by designing the arrangement position of the dipole unit and finally feeding it with one port. The design features six pairs of modified cross dipoles arranged along a parallel feeding wire transmission line, with six dipole elements positioned in two orthogonal planes. The antenna array is fabricated by 1 mm diameter copper wire and fed by a coaxial structure at the center of the array. The maximum cross-section area is $3.17 \times 0.5\lambda^2$ (at the designed frequency of 4 GHz), enabling easy implementation within a cylinder. Measurements and simulations have been conducted to validate the antenna. The 10 dB impedance bandwidth is 26.89%, ranging from 3.83 to 5.02 GHz, with a measured peak realized gain (RG) of 7.44 dBi. Furthermore, the measured 1 dB gain bandwidth of the proposed antenna is 1 GHz (22%), spanning from 4 to 5 GHz. The combination of high gain, wide bandwidth, omnidirectional radiation, and cost-effectiveness renders this antenna array suitable for base station applications.

Key words　Omnidirectional patterns, Series-fed dipole array, Broadband, Sub-6 band, Base station

1. Introduction

Omnidirectional antennas are popular applications in wireless communications where full coverage of the surrounding environment is required, such as cell phones, base stations and WLAN. While vertically polarized omnidirectional antennas are readily realized through monopole and biconical designs [1]-[4], generating horizontally polarized (HP) omnidirectional radiation requires array antennas such as cylindrical slit arrays, cylindrical microstrip arrays, turnstile antennas, and Alford loops [5]-[8], due to the absence of magnetic dipoles. Broadening the bandwidth of such antennas can be accomplished using parasitic elements. However, a persistent challenge is the limited peak gain of these antennas, often falling below 4 dBi. Even the average gain tends to be lower.

Achieving sufficient gain in base station antennas for wide coverage is crucial, yet limited research has addressed this. Researchers have leveraged designed HP antennas to form arrays, yielding higher gains. For instance, [9] introduces a broadband OHP planar antenna using arc dipoles, achieving an 8 dBi peak gain. However, the size exceeds 6λ and requires multiple feeding cables, adding complexity. The traveling wave antenna also achieves high-gain OHP radiation [10], but its beam pattern shifts with frequencies. Some studies explore magnetic dipoles (MD) for HP realization [11-12]. In [12], the substrate integrated waveguide (SIW) creates in-phase MDs, resulting in a 4.3λ antenna with the gain of 10.4 dBi. However, the metal vias demand precision. A slender Fabry-Perot antenna is also used for high-gain OHP radiation [13], attaining 10 dB impedance bandwidth (2.41 to 2.5 GHz) with 8.52 dBi gain. Despite its compact 2.95λ size, a drawback is the narrow bandwidth (3.75%) [13].

In this paper, a novel feeding method is proposed for achieving a broadband series-fed antenna with an omnidirectional radiation pattern, taking inspiration from the turnstile antenna concept. According to transmission line theory, the 90 deg phase difference is achieved by putting the crossed dipoles at a distance of a quarter wavelength. Experimental measurements demonstrated a relative impedance bandwidth of 26.89% (3.83 to 5.02 GHz). The peak realized gain (RG) value measured at the desired frequency is 7.44 dBi, exhibiting a 1 dB gain bandwidth of 1 GHz (22%), spanning from 4 to 5 GHz, indicating its capability to maintain a high gain over a wide frequency range.

2. Design of Omni Broadband Series-fed Antenna

2.1 Modified Turnstile Feeding

Conventional turnstile antennas achieve a 90-degree phase difference by using multiple feed lines [14–18] or adjusting the length of crossed dipoles [19]. We would like to apply the turnstile feeding method to a compact series-fed antenna array with only one port in the center to realize the excitation of all dipole units, which effectively reduces the cables and power dividers.

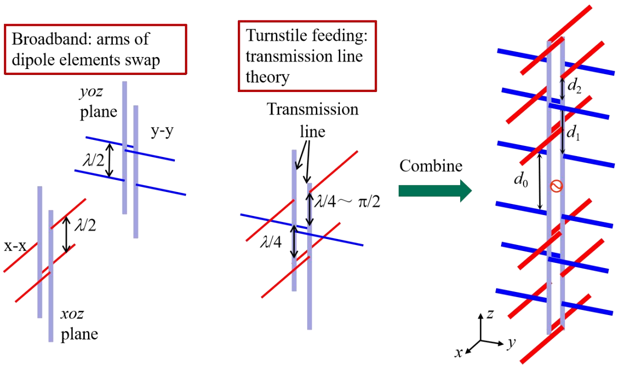

Fig. 1 Arrangement of the dipole units.

In Fig. 1, the transmission line theory is utilized to achieve a 90-degree phase difference in series-fed array. By employing a quarter-wavelength transmission line, which introduces a 90-degree phase change, the necessary phase difference can be achieved. The crossed dipoles are then positioned at a distance equivalent to a quarter wavelength. This configuration ensures that the 90-degree phase change occurs between the two crossed dipoles, meanwhile all of the cross dipoles with 90 degree phase difference can be excited by single port.

2.2 Broadband Realization

The modified self-complementary cross dipole structure is used to achieve broadband performance. There is a 180-degree phase change in Fig. 1 as a result of the arms of neighboring dipole components on each plane being switched. Another 180-degree phase change is added by positioning neighboring parts in the same plane half a wavelength apart. Thus, it is possible to accomplish in-phase radiation of the components on the same plane, allowing for the creation of a high-gain radiation pattern.

Broadband property is made possible by the idea of switching the arms and keeping a certain distance between neighboring parts. Additionally, it enables the unit spacing to be shortened from one wavelength to half a wavelength, which may significantly lessen radiation toward top direction and concentrate energy on the horizontal plane.

2.3 Antenna Parameters

The antenna's general structure is shown in Fig. 2. Six crossed pairs of dipoles, each with a length of $\lambda/2$ (at the designed frequency of 4 GHz), make up the antenna. Transmission lines are used to connect these crossed dipoles, which only need one port. To achieve the necessary phase shifts, the arms of neighboring components within each pair of crossed dipoles are switched. Different colors representing a crossed pair of dipoles with a spacing of $\lambda/4$ are displayed. Contrarily, similar items are shown in the same color, resulting in a $\lambda/2$ separation distance. The particular parameter values related to the antenna design are shown in Table 1.

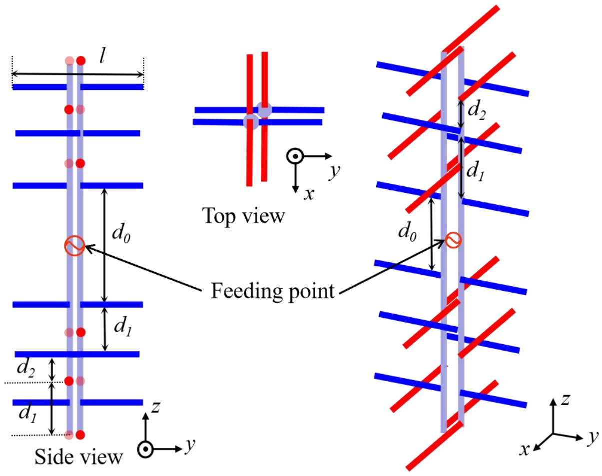

Fig. 2 Overall structure of the proposed antenna.

Table 1 Parameters of the proposed antenna.

Para-meter	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

3. Processing and Measurement

The proposed antenna is made of 1 mm diameter copper wire and excited by a coaxial line in Fig. 3. The experimental setup for evaluating the proposed antenna via a 2-port VNA (Anritsu MS46122B). The proposed antenna is placed on the turntable. A standard horn antenna is used as the receiving antenna. To reduce cable losses, the VNA is placed in an electromagnetic anechoic chamber covered with absorbing material.

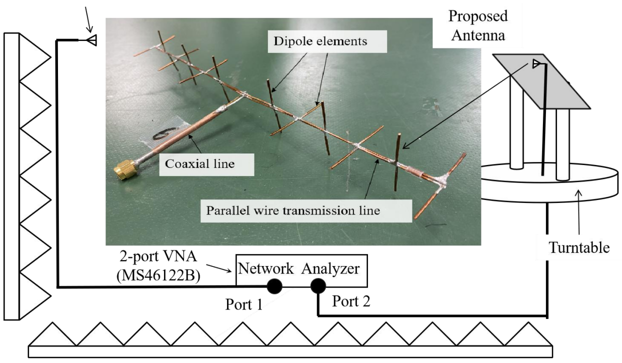

Fig. 3 Fabrication and experimental setup.

The features of reflection coefficient are shown in Fig. 4. The blue line depicts the simulated result, while the red line the measured result. A relative impedance bandwidth of 26.89% is produced by the observed 10 dB impedance bandwidth, which ranges from 3.83 to 5.02 GHz.

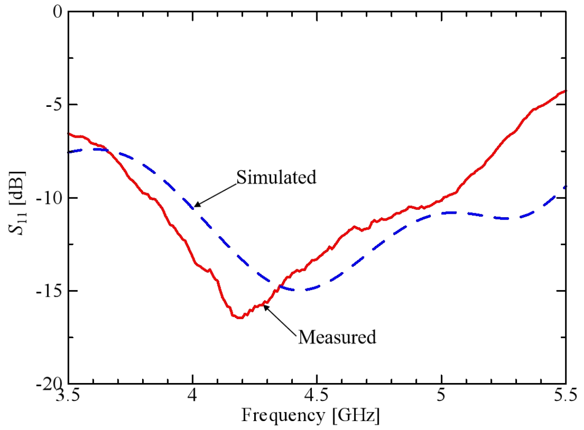

Fig. 4 Reflection coefficient.

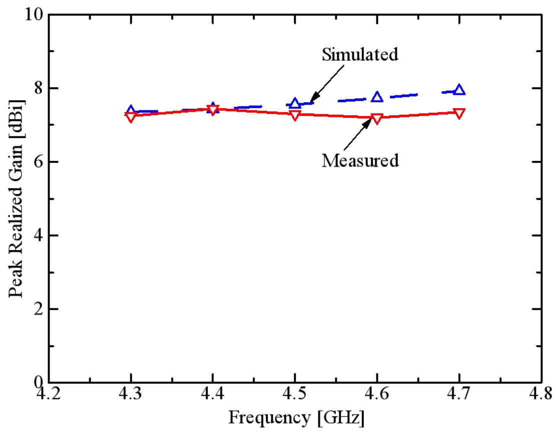

Fig. 5 Peak realized gain in horizontal plane.

The measured peak realized gain (RG), which occurs at 4.4 GHz in Fig. 5, is 7.44 dBi. Furthermore, the 1 dB bandwidth is observed of 22%. This shows that the antenna can sustain a pretty high gain throughout its working frequency range.

Fig. 6 depicts the radiation patterns of the antenna at different frequencies. The comparison between simulated and measured result is observed and a good agreement is observed. However, it is worth noting that there is a slightly larger error at high frequencies. It is because of hand-made.Whether the position and angle of the units are accurate in the processing will affect the measured results of the antenna. Especially in the series-fed antenna, the accumulated errors are more obvious in the high frequency band. The antenna is likewise composed of 1 mm diameter copper wire, which is rather flexible and makes it easier to solder, thus a minor bend will also cause the radiation patterns to be deflected.

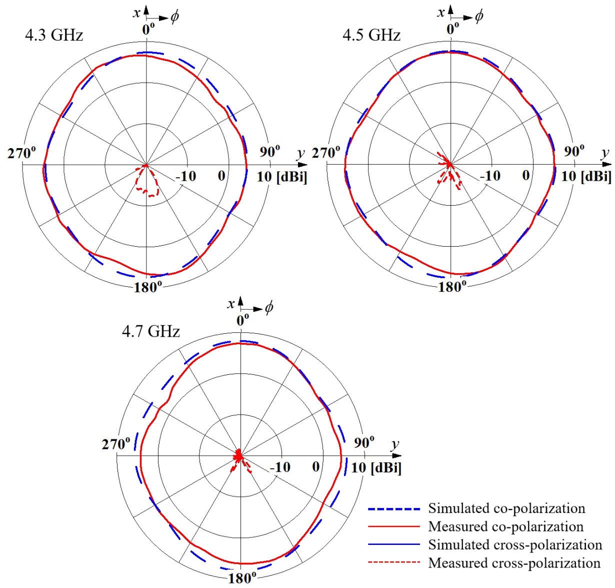

Fig. 6 Radiation patterns in horizontal plane.

4. Conclusion

A novel feeding method for omnidirectional series-fed broadband dipole array antennas is proposed in this paper. Drawing inspiration from the feeding technique of the turnstile antenna, the omnidirectional radiation is achieved by strategically arranging the dipole units. Experimental results confirmed that the antenna achieved 10 dB impedance bandwidth of 26.9% (3.83-5.02 GHz). The measured maximum gain reached 7.44 dBi, with a 1 dB gain bandwidth of 22%. The experimental and calculated results exhibited good agreement, showcasing the feasibility of the proposed series-fed broadband omnidirectional antenna design.

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