A Millimeter-wave Windmill-shaped Magnetoelectric-dipole Antenna with Broadband Circular Polarization and Wide Axial-ratio Beamwidth

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ABSTRACT

A millimeter-wave (MMW) windmill-shaped magnetoelectric-dipole antenna with broadband circular polarization and wide axial-ratio (AR) beamwidth is presented. Good circular polarization performances of the proposed antenna are contributed to excellent performances of the magnetoelectric-dipole, the benefit of windmill shape and the sequential feed scheme by a circular microstrip line. Simulation results show that the antenna obtains a wide impedance bandwidth of 58.8% over the band 30~55 GHz, a stable 3-dB AR bandwidth of 30% across the band 34~46 GHz. And the gain is higher than 6 dBi within the AR bandwidth, with the highest gain of 9.2 dBi at 45 GHz. In addition, a unidirectional and stable pattern has also been achieved.

KEYWORDS

Millimeter-wave (MMW), Magnetoelectric-dipole, Circular polarization, Broadband, Wide axial-ratio (AR) beamwidth.

INTRODUCTION

Millimeter wave (MMW) bands can achieve high data rate and high capacity compared with its lower frequency counterparts. It has attracted much attention and been widely used in various fields such as satellite communication, radar, high-precision guidance, and 5G mobile communication. Moreover, CP antennas are usually used to add additional advantages for mobile wireless devices because CP signals provide better propagation characteristics in multipath environments compared to the linearly polarized ones[1].

Up to now, many designs have been proposed for circular polarization. In reference to planar antennas, patch antennas[2-3] and slot antennas[4-5] are usually designed for circular polarization. One of the most important aims of these designs is to broaden the bandwidth. However, the AR bandwidth of patch antennas is generally less than 20%. Slot antennas could reach an ultra-wide bandwidth of more
than 100%, but their radiations are bi-directional. Generally, AR beamwidth wasn’t considered in those designs and good circular polarization only maintained around the zenith, which would deteriorate the performances outside the coverage center. In recent years, due to the advantages of broadband, unidirectional, stable, symmetric radiation pattern and low cross polarization, magnetoelectric dipoles are designed to obtain circular polarization. A wideband CP magnetoelectric dipole antenna had achieved a 3-dB AR bandwidth of 45.3% from 1.45 GHz to 2.3 GHz[6], but it worked at lower frequency. A magnetoelectric dipole antenna operating at Ku-Band obtained an unstable gain during the band[7]. Therefore, the antenna with good performances in terms of broadband circular polarization, wide AR beamwidth, unidirectional and stable radiation pattern is desirable for 5G communication in MMW band.

In this letter, a MMW windmill-shaped magnetoelectric-dipole antenna with broadband circular polarization and wide AR beamwidth is proposed. The remainder of this letter is organized as follows. Section II describes the antenna configuration. In section III, the antenna performances are illustrated by simulation results. Finally, the conclusion is given in section IV.

ANTENNA DESIGN

The configuration of the proposed antenna is shown in Figure 1. From the up down, the antenna consists of two crossing magnetoelectric dipoles and a microstrip line, which are curved on two substrates. The two crossing magnetoelectric dipoles are constructed by four windmill-shaped horizontal electrical dipoles and four poles. The windmill shape is formed by a circular patch cut by four curves, each of which is combined by a circular arc and a straight line. The angles of adjacent circular arc are different for more variations to optimize the circular polarization. And the four curves are symmetric along the diagonal. Four poles with the same dimensions are placed symmetrically and connected to the microstrip line below. The feeding microstrip line with five sections of different widths is designed to obtain good matching in broadband. In this design, two Rogers 5880 PCB substrates with a relative dielectric constant of 2.2 are used.
TABLE I. OPTIMIZED PARAMETERS OF THE PROPOSED ANTENNA.

| Parameters | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $L_1$ | $L_2$ | $d_8$ |
|------------|-------|-------|-------|-------|-------|-------|-------|
| Values/mm  | 1.60  | 0.75  | 0.60  | 0.85  | 7.64  | 9.08  | 0.4   |
| Parameters | $d_1$ | $d_2$ | $d_3$ | $d_4$ | $d_5$ | $d_6$ | $d_7$ |
| Values/mm  | 0.2   | 0.32  | 0.29  | 0.30  | 0.33  | 0.33  | 0.30  |
| Parameters | $h_1$ | $h_2$ | $\alpha$ | $\beta$ | $\gamma$ |
| Values/mm  | 1     | 0.25  | 131°  | 116°  | 90°   |

SIMULATION RESULTS

The simulation results of the antenna are illustrated in this section. The optimization of the proposed antenna is carried out with the assistance of a full-wave electromagnetic solver CST 2017. Based on the optimized values listed in Table I, the simulation results of the antenna in terms of $S_{11}$, radiation pattern, gain, AR bandwidth and AR beam width are illustrated as follows.

Figure 2 shows the simulated reflection coefficient $S_{11}$ of the antenna. It’s found that the simulated impedance bandwidth for $S_{11}$ better than -10 dB is 58.8% from 30 GHz to 55 GHz. The broadband impedance bandwidth is contributed to the sequentially fed scheme and the multi-section impedance matching line.
Figure 2. The simulated reflection coefficient $S_{11}$ of the proposed antenna.

Figure 3 shows the radiation pattern at 35 GHz, 40 GHz, 45 GHz in the phi = 0° and phi = 90° plane. It can be seen that the antenna achieves a stable radiation pattern with its 3-dB beamwidth around 70° across the AR bandwidth, which corresponds to the characteristics of magnetoelectric dipoles. It is a little deteriorated when the frequency shifts up. That’s because the electrical lengths of magnetoelectric dipoles change with the frequency.

Figure 3. Radiation pattern of the proposed antenna. (a) 35GHz, (b) 40 GHz, (c) 45GHz.

Figure 4 depicts the simulated directivity and gain of the antenna. The gain is higher than 6 dBiC over the AR bandwidth with the highest gain at 45 GHz. The gain is lower than the directivity about 0.3-0.6 dBiC across the AR bandwidth, which is related to an efficiency of 91%-97%. The efficiency is high at MMW, due to its compact and simple structure with less parasitic radiation. The gain turns down when the frequency shifts up from 45 GHz, due to the deterioration of pattern.

Figure 5 illustrates the simulated AR at the zenith versus frequency. It can be seen that the simulated 3-dB AR band is 30% from 34 GHz to 46 GHz. And the broadband AR bandwidth is contributed to the sequentially fed circular microstrip line with good matching.
Figure 4. Directivity and gain versus frequency.

Figure 5. Axial-ratio at the zenith versus frequency.

Figure 6 shows the AR beamwidth at the frequency of 35 GHz, 40 GHz, 45 GHz. It can be seen that the AR beamwidth is about $60^\circ$-$112^\circ$ in the phi=$0^\circ$ plane and $41^\circ$-$60^\circ$ in the phi=$90^\circ$ plane. The wide AR beamwidth is contributed to the windwill-shaped electrical dipoles, which guide the current to a circular mode.

Figure 6. Axial-ratio in the phi = $0^\circ$ and phi = $90^\circ$ planes. (a) 35 GHz, (b) 40 GHz, (c) 45 GHz.
CONCLUSION

A MMW windmill-shaped magnetoelectric-dipole antenna is proposed in this letter, which achieves broadband circular polarization with wide AR beamwidth. Besides, the antenna has a compact and simple structure with a single microstrip feed, which is very desirable for 5G antenna arrays.

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