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A Millimeter-Wave Resonant Cavity Antenna with High Gain and Low Sidelobe Level

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Abstract

This paper presents a Millimeter-Wave (mm-wave) resonat cavity (RC) structure with high gain and low sidelobe level (SLL). It consists of a 5×5 dipole antenna array as a main radiator fed by a series feeding network. The network is designed based on the Chebyshev distribution to decrease the SLL. A partially reflective surface (PRS) is designed and placed above the dipole array to improve the RC radiation characteristics. All dipoles arranged in a separated row are connected by a series network with Chebyshev distribution weights. A vertically-placed series feeding network is applied to feed all five rows of the dipole array and is enclosed by a metallic cavity to decrease the undesired backward radiations resulting from the vertical feeding line. It is observed that the sidelobe level can be reduced to -32 dB and -27 dB at E-plane and H-plane, respectively. Also, a high gain of 22 dBi is achieved at 28 GHz.

1 Introduction

Millimeter-Wave spectrum offers a potential solution to wideband 5G applications. Despite the advantages the mm-wave spectrum brings, several potential challenges have been remained unsolved for communications. The path loss and weaker penetration through objects require new solutions to emerge. Antennas with high directivity and low SLL are promising solution to mitigate the mentioned concerns at the mm-wave frequencies band and maintain the link budget.

Resonant cavity structures are suitable candidates to meet the requirements of the communication systems over the mm-wave spectrum for 5G applications [1, 2, 3]. Resonant cavity antennas have grown attention due to their planar configuration, low fabrication difficulty, high-gain characteristic and their capability of integration with other systems. Different feeding techniques and radiating elements to illuminate the PRS layer have been proposed to improve the radiation performance of RC structures. Open-ended waveguide [4], patch antenna [5], stacked antenna [6], dielectric resonant antenna (DRA), dipole antenna, and crossed bowtie dipole [7] can be used as the main radiating element inside the cavity.

Using an array of radiating elements replacing a single radiating element to illuminate the PRS in an RC structure is one of the approaches to provide further improving radiation characteristics [8, 9, 10]. However, the arrangement of radiating elements in an array structure contributes to high SLL, which results in interference by the other signals and the waste of the energy. There are a variety of methods to feed an array of radiating elements with the aim of low SLL. Amplitude weighting methods such as Binomial, Chebyshev, and Taylor have been considered as effective and applicable methods to lower sidelobe level. Chebyshev is among the best and well-known methods where higher directivity with lower SLL is required.

For array antenna structures, using corporate feeding network is a common approach in which a conventional Wilkinson power divider can be used to realize certain amplitudes of power to single radiating element [11]. Although this technique allows the antenna array to have in-phase excitation of single elements in a wide bandwidth, it has low efficiency due to dissipation losses within large feeding network [12, 13, 14]. In order to decrease the dissipation losses, a series feeding network can be utilized. This configuration in addition to providing simple and miniaturized feeding network [15, 16] enhances antenna efficiency, since the length of feeding network is significantly reduced respect to conventional corporate feed counterparts [15, 16, 17]. Besides, it can reduce the unwanted coupling between radiating elements and feeding network [18].

In this paper, an RC structure with an array of 5×5 printed dipoles as the main radiating element is presented to achieve high gain over the millimetre wave spectrum. To reduce the SLL, a series fed network is designed so that the output powers are proportional to the Chebyshev distribution with the aim of improving SLL better than -30 dB. The proposed structure consists of a PRS layer illuminated by the array antenna. The proposed antenna obtains sidelobe level of -32 dB and -27 dB at E-plane and H-plane, respectively. Besides, a maximum antenna gain of 22 dBi is achieved at 28 GHz.

2 Proposed RCA Structure

The proposed RC structure consists of a PRS, an array of dipole antennas as the radiating elements, and a series feed network based on the Chebyshev distributions as shown in Fig. 1.

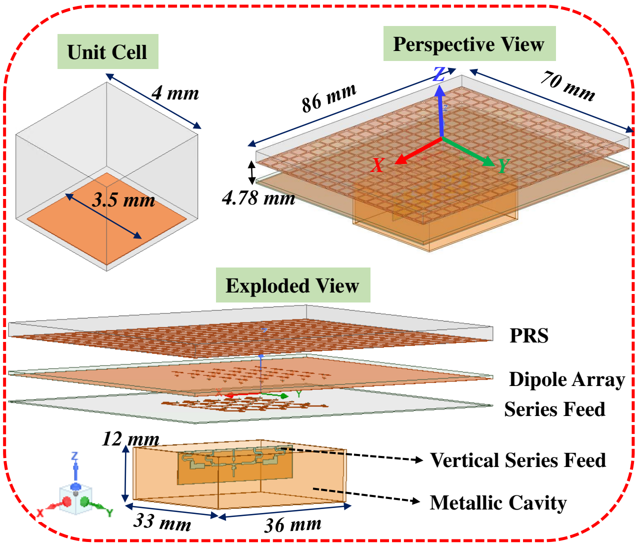

Figure 1. The structure of the proposed RC structure.

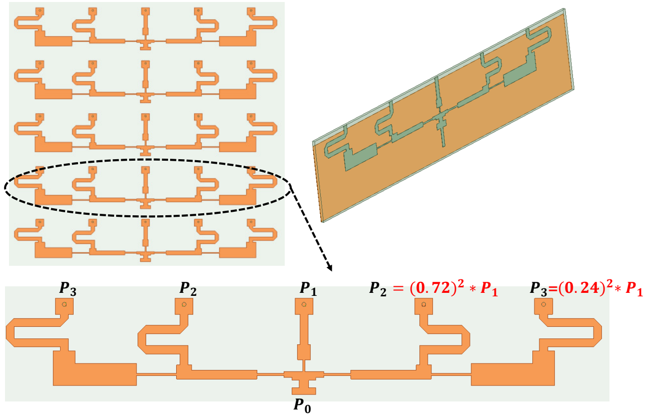

Figure 3. Feeding network.

A single-layer one-sided PRS unit cell with a thin thickness is proposed. The schematic of the proposed PRS unit cell is shown in Fig. 1. A metallic patch is printed on one side of a Rogers 5880 substrate with a thickness of 3.2 mm, relative permitivity of 2.2, and loss tangent of 0.0027. An array of 5×5 dipoles are arranged in both X and Y axes with a distance of 6 mm as shown in Fig. 2. Also, the schematic of a single dipole is shown in Fig. 2. Although both electric and magnetic dipoles [19] can be used as radiating elements, electric dipoles have been chosen due to easier fabrication. The dipole is etched on a Rogers 5880 substrate with a thickness of 0.787 mm. The right arm of the dipole is connected to the ground plane by a via, and the left arm is connected to a feed line behind the ground plane separated by a Rogers 5880 substrate with a thickness of 0.274 mm. In fact, the series feeding network based on the Chebyshev factors is etched on this layer. The feeding network is placed below the array antenna as demonstrated in Fig. 1. Another via is used to connect the left arm to the ground plane. It should be noted that the position of both left and right vias are adjusted so that the dipole becomes a balanced structure to have equal current in both arms. The elements of array are connected by the series fed network and a vertical series fed is placed beneath the entire structure to connect the series fed network to a coaxial probe. Although this part can be attached to the entire feeding network at the same plane, it is placed behind the structure to minimize the undesired radiation resulted from the entire feeding network. Also, the vertical part is enclosed by a metallic cavity to minimize further undesired radiation. The series fed network is shown in Fig. 3. The outputs powers are calculated based on SLL=-30 dB for five radiating elements. All feeding branches have the same dimensions. Also, all elements are in-phase. The output power corresponding to the Chebyshev coefficients are shown in Fig. 3. Based on these Chebyshev distribution weights, we need to realize the following power distribution for the 30 dB SLL: that:

$$P_2 = (0.72)^2 * P_1 \quad and \quad P_3 = (0.24)^2 * P_1 \tag{1}$$

Thus, based on (1), the S-Parameters of the feeding network

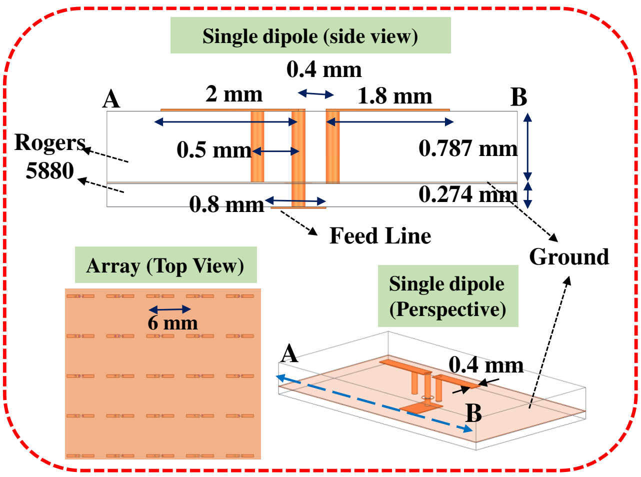

Figure 2. Array antenna and single radiating element.

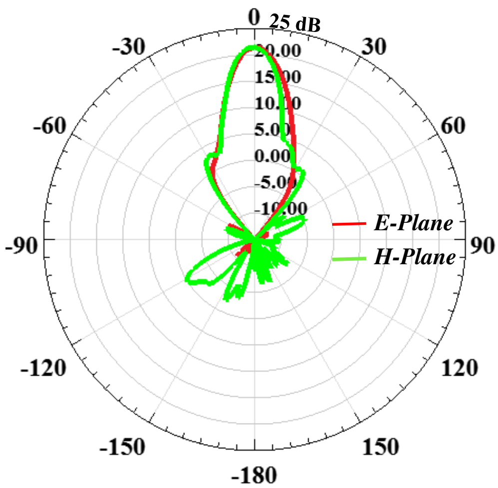

Figure 4. Antenna gain pattern at 28 GHz.

at 28 GHz can be calculated by:

$$S_{10} = -3.37\ dB,\ S_{20} = -6.2\ dB,\ S_{30} = -15.7\ dB \quad (2)$$

It should be noted that all outputs should be in-phase. The proposed RC structure is simulated by Ansys HFSS. The antenna patterns at both E-plane and H-plane at 28 GHz are demonstrated in Fig. 4. As shown, the maximum antenna gain is 22 dBi at 28 GHz, with a SLL lower than -32 dB and -27 dB at H-plane and E-plane, respectively.

3 Conclusion

In this work, the design of an RC structure with high gain and low SLL over millimeter wave frequencies is presented. As the main radiator, an array of dipols is used, which are fed by a series fed network based on the Chebyshev distribution weights. This way, the antenna radiation characteristics is improved while the sidelobe level is kept low. Besides, to minimize the undesired radiations resulted from the series fed network, a portion of feeding network is vertically installed behind the entire structure surrounded by a metallic cavity. A maximum gain of 22 dBi and a low sidelobe level of -32 dB at 28 GHz are achieved. The proposed antenna has potential application for 5G communication systems.

4 Acknowledgment

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