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# A Millimeter-Wave Dual Band Antenna with Circular Polarization

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**Abstract**—This paper presents a high efficiency dual band single layer antenna structure for MIMO array applications. The e-shape patch that is surrounded by two conductive walls is designed on an RO5880 substrate with thickness of 0.508 mm. The operating frequencies of this antenna are 28 GHz and 38 GHz. Circular polarization is achieved by designing the specific shape of the inner patch and cutting the edge of the outer ring. The reflection coefficient is less than -10 dB at 25.9-28.6 GHz and 36-58.5 GHz with maximum gain and efficiency of 6.31 dB and 92% at 28 GHz and 5.2 dB and 71% at 38 GHz. This low-profile and lightweight antenna can be used in many 5G communication systems.

**Index Terms**—circular polarization, dual band, high efficiency, patch antenna, single layer antenna.

## I. INTRODUCTION

The attention to 5G is growing because of the demand for high data rates and reliability of this generation compared to its predecessors. Besides, there are many frequencies that can be allocated to specific applications in the future [1]. Due to the huge bandwidth available at millimeter-waves (mm-waves) that varies between 30 and 300 GHz, the need for more mobile traffic can be achieved by utilizing such bandwidth at these high frequencies for 5G communications. The frequency bands of 28 GHz, 38 GHz and 60 GHz are adapted for this generation of communication [1].

The main idea of using directional antennas in this range of frequencies is to suppress the interference from co-channels in free space communications. One architecture to achieve this goal is multi-layered stacked patch antennas [2]. In some designs of these structures, the ground is on the top of the first layer and feeding is placed on the opposite side which couples to the patch where also a frequency selective surface (FSS) layer is used through a small slot in the ground plane to achieve a highly directive antenna [3].

Another structure used the ground on the bottom layer and microstrip feeding on the opposite side to excite two patch layers located on the top of it with air space [4]. For getting more directional radiation, a stacked yagi antenna was proposed where several directors are located on its top and the feeding is simple [5], or complicated via the use of magneto electric dipole with a T shape coupled strip to get better efficiency and bandwidth [6], [7]. As circularly polarized antennas have more advantages compared to linear or elliptically polarized ones, in terms of immunity to Faraday

rotation, reduction of interference between the direct and reflect radiation, and independence to antenna alignment, many applications and standards prefer this kind of antenna [8]. By using a slot in the ground of the substrate or in the path of a radiating beam the linear polarization can be transformed into circular polarization [9]. Another method is by feeding the structure with two orthogonal modes that excites the antenna with two orthogonal E-fields [10]. Integrating some rings between the layers that consist of corner cut patch shape can generate a circularly polarized antenna as well [11].

However, all of these mentioned structures are either large in size with several layers that are not suitable to implement in tiny devices at mm wave ranges or they are single band that do not meet our demand of working at dual band. There are several challenges for designing a dual band antenna that operates at high frequency with acceptable efficiency and small size. The first challenge is the dimension which should be as miniature as possible in order to use it in small communication systems of 5G and in the meanwhile satisfies the requirements of high gain and high efficiency. Another challenge is the polarization of this antenna, to enable it for use in various wireless or radar systems without worrying about the alignment of the antenna at the receiver or transmitter. In this paper, a novel e-shape single layer patch antenna with high efficiency and circular polarization is proposed. Section II shows the architecture of this antenna and its parameter effects. Then simulation results are investigated in details. Section IV presents the conclusion.

## II. CONFIGURATION

The purpose of this work is designing dual band antenna that operates at 28 GHz and 38GHz. Fig.1 shows the top layer of the antenna that consists of three separate shapes of perfect electric conductive material, a rectangular ring that has two corners cut and an e-shape patch located in the middle of the structure. The substrate material is Rogers 5880 with thickness of 0.508 mm and permittivity of 2.2.

The design is first optimized for 28 GHz that is the lower frequency in this work and then for the higher frequency of 38 GHz. For this goal, the dimension of substrate is selected 7 by 5.5 mm. Two L-shaped structures are optimized for operating at 28 GHz with circular polarization. The e-shape placed in the centre of the design is for achieving two goals, first wide bandwidth and second circular polarization at 38 GHz. The



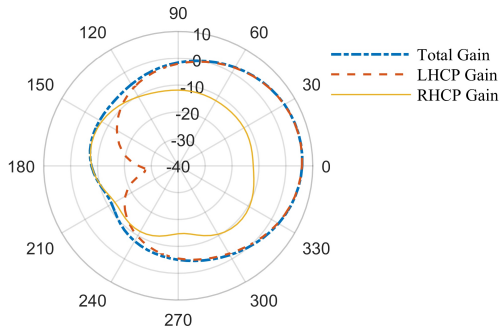


Fig. 6. Simulated radiation patterns of single element antenna at 28 GHz for  $\phi = -15$  degree.

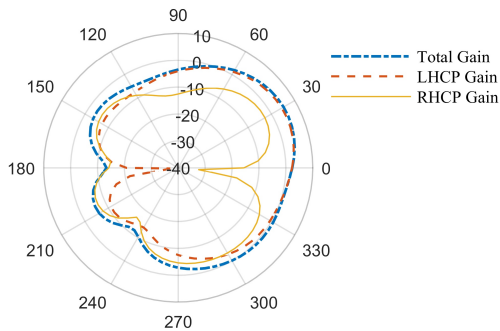


Fig. 7. Simulated radiation patterns of single element antenna at 38 GHz for  $\phi = -75$  degree.

the structure shows dual band operation with wide bandwidth at the higher frequency with a value of 22.5 GHz. The L-shaped wall dimensions have strong influence on the reflection coefficient at the lower frequency while the patch in the middle is designed for wide bandwidth at the higher frequency.

As the proposed antenna is so small, the coax feeding might influence the radiation properties. In general, the dimensions of the feeding should not be so close to the dimensions of the structure since it might affect the antenna performance. In order to show the influence of the coax on the output results of the antenna we excite the structure with an ideal discrete port. Fig. 5 shows the reflection coefficient of the antenna with discrete feeding. It can be observed that the influence of the coax feeding is substantial. That is why all the optimization was conducted in the presence of the connector coax model. As our main goal of designing this single element antenna is using it as one element in an array in the future work, we should know the stability of the response when they are implemented in the array. The increased ground size is the evidence that the frequency response of this antenna is stable over frequency, as shown in Fig. 5, and the resonances occur at 28 and 38 GHz with mostly same bandwidth compared to the non-increased size. Here the dimension of substrate and ground is increased two times without changing the substrate thickness.

### C. Efficiency and Gain

The ratio of the radiation power to the input power is 92% and 71% at 28 GHz and 38 GHz, respectively. This efficiency is always more than total efficiency because of the impedance mismatch. The total efficiency for this antenna including feeding mismatch is 90% and 68% at 28 GHz and 38 GHz, respectively. The gain of this single element antenna is shown in Fig. 6 with the maximum total gain of 6.31 dB at 28 GHz. This antenna is left-handed circular polarized (LHCP) antenna, as you can see in Fig. 6, the LHCP component is in our desirable direction with maximum gain. The total gain for CP antenna can be calculated as the sum of partial gains of two orthogonal polarizations. Then, because of the crosspolarization (RHCP) loss, the co-polarization (LHCP) gain is a bit lower than the total gain with the maximum of 6.24 dB. The maximum total gain at 38 GHz is 5.2 dB as shown in the Fig.7 with LHCP gain of 4.48 dB.

The fabricated prototype and measurement results will be shown and discussed in the conference presentation.

## IV. CONCLUSION

A novel dual band antenna structure with high efficiency and circular polarization is proposed that can be implemented in many small devices due to its low-profile. This antenna operates at 28 GHz and 38 GHz with high gain and efficiency of 6.31 dB and 92% at the first band and wide bandwidth of 22.5 GHz and high efficiency at the second band. Circular polarization was achieved by designing the specific e-shaped patch and cutting the corners of the outer rectangular ring to change the direction of the current distribution for creating circular E-field radiation. Several numbers of this single element antenna can be used in phased array structure of MIMO systems to satisfy high data rate demands of 5G communication.

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