Differentially-Driven Circularly-Polarized Planar Aperture Antenna for Millimeter-Wave Application

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Abstract—**This paper presents a novel differentially-driven planar aperture antenna for circularly-polarized (CP) radiation. The proposed antenna is simple in structure and is constructed on only a single layer laminate using standard printed-circuit-board (PCB) technology. Circular polarization is realized by rotationally-symmetric windmill-shaped aperture-strip formation with travelling wave distribution. An opening-cavity that is formed by metalized vias is adopted to offer favorable unidirectional radiation and higher gain. Simulation results of a prototype working at V-band show a 3-dB axial ratio (AR) bandwidth of 17.4% (56.8–67.5 GHz), which is within its -10-dB impedance bandwidth. Meanwhile, the left-handed CP (LHCP) gain is stable throughout the operating bandwidth with a peak gain of 14.2 dBi. The proposed antenna is a promising candidate for millimeter-wave (mmWave) bands due to its merits of wideband, high gain, simple structure, low cost, and easy integration with differential circuits.**

I. INTRODUCTION

APERTURE antennas, such as horn and parabolic reflector antennas are widely used for millimeter-wave (mmWave) applications due to their high gain, wide bandwidth, and relatively simple structure. These, however, usually have high profile, large size and high cost, which makes them not suitable for consumer level mmWave products [1]. In order to overcome these drawbacks, we have recently proposed a new type of planar aperture antenna with broadside radiation [2]. The antenna is compact, high gain, wideband and realized using only a single layer laminate via standard printed-circuit-board (PCB) technology for low cost. However, similar to its former counterparts [3–5], it is linearly polarized (LP), which makes it unsuitable for some applications requiring circularly polarized (CP) radiation [6]. In fact, there is still much need for research on high-performance and low-cost CP planar aperture antennas, especially at mmWave bands.

In this work, a new differentially-driven planar aperture antenna capable of CP radiation and suitable for consumer level mmWave applications is proposed. CP radiation helps reduce loss due misalignment between transmitter and receiver antennas and loss due multipath interferences whereas differential feeding eliminates the need for bulky off-chip and lossy on-chip baluns when integrating the antenna with differential mmWave monolithic integrated circuits, and offers high polarization purity [7, 8].

II. ANTENNA DESIGN

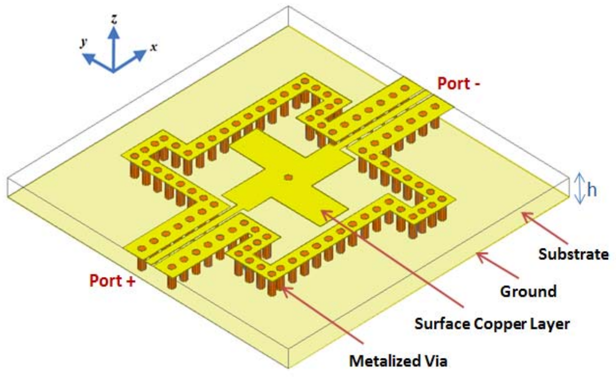

Fig. 1. Geometry of the proposed CP planar aperture antenna.

The geometry of the proposed antenna is shown in Fig. 1. Similar to [2], the proposed antenna has a long patch that excites a uniform aperture field (corresponding to the highest aperture efficiency) in a large physical aperture, about $2\lambda_0$ in diameter, which guarantees high gain at broadside direction. It also adopts an opening cavity with a height of one quarter of guided wavelength ($\lambda_g/4$) at operating frequency, which ensures the highest aperture E-field amplitude. The fields, however, are altered to support two orthogonal modes with comparable magnitudes and quadrature-phase difference, which gives rise to CP radiation. This is done by adopting the special 180° rotationally-symmetric windmill-shaped patch-aperture formation.

The patch carries traveling wave energy into and within the antenna’s aperture, hence it acts as both transmission body and radiator, whereas the opening of the cavity and its peripheral make the physical aperture of the proposed antenna, through which energy is mainly radiated. The opening cavity is formed by metalized vias and the patch is outer-fed using grounded co-planar waveguide (GCPW) for low transmission loss. The center of the patch is the virtual AC grounded point, thus it is shorted by a metalized via to reduce the effect in the case that the input signal is not a perfect differential signal. Using differential feed leads to more even energy transfer to the antenna structure, which as a result grantees the purity of the excited modes and hence improves the CP performance.

Since $\lambda_g/4$ at mmWave bands approximately corresponds to the thickness of most commercially available laminates, such as, RT/Duroid 5880 and 6010, the proposed aperture antenna is compatible with standard planar circuit technology at mmWave band. A prototype of the proposed antenna operated at 60 GHz band was implemented using a single layer ROGERS 5880 laminate ($\varepsilon_r = 2.2$, $tan\delta = 0.0009$, and thickness h = 0.787 mm). The size of the antenna’s opening cavity is 10mm×9.1mm while the size of the ground plane is 14mm×14mm.

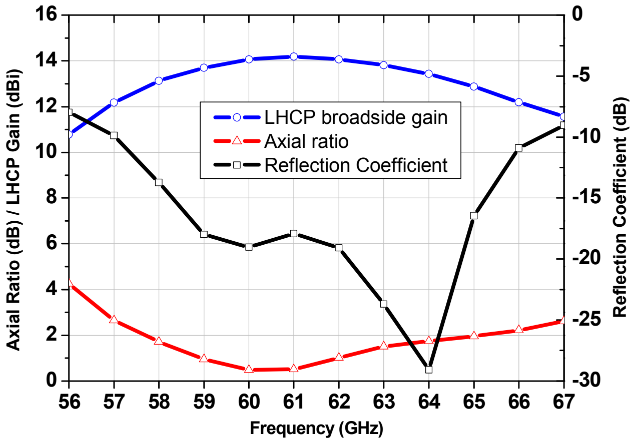

Fig. 2. Simulated reflection coefficient, axial ratio and broadside gain of the proposed CP planar aperture antenna.

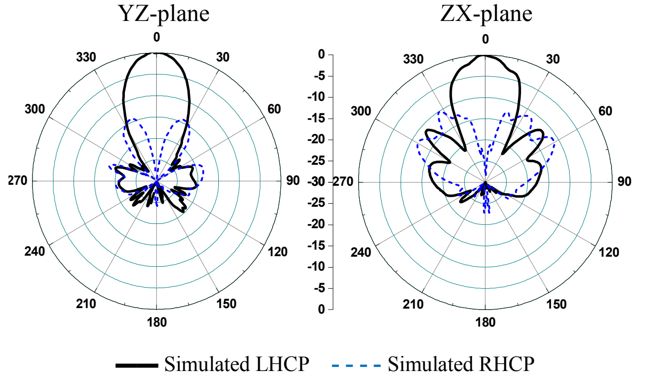

Fig. 3. Simulated radiation patterns of the proposed CP planar aperture antenna at 61 GHz.

III. PERFORMANCE RESULTS

The proposed antenna was designed and optimized to work at V-band through simulations using the commercial electromagnetic (EM) software Ansys HFSS. Simulated results of reflection coefficient, axial ratio and broadside gain are shown in Fig. 2. The impedance bandwidth (S_{dd11}<-10-dB) of the antenna is 17% ranging from 57 to 66.5 GHz. The axial ratio bandwidth (AR<3-dB) is 17.4% ranging from 56.8 to 67.5 GHz. Meanwhile, the left-handed CP (LHCP) gain's half power bandwidth is 18% ranging from 56.3 to 67.4 GHz. The antenna has a maximum gain of 14.2 dBi occurring at 61 GHz.

Fig. 3 shows the radiation patterns of the proposed antenna at the center frequency of 61 GHz at both YZ- and ZX-planes normalized using the peak gain. It can be seen that the radiation patterns at both planes are symmetric and maximum gain is fixed in the broadside direction. Cross polarization is the lowest at the +z-direction as expected and larger at lower elevation angles on both sides of the z-axis. Meanwhile, simulated results show a very small back lobe with a front-to-back ratio larger than 22 dB in both planes. It is noted that radiation patterns at both planes are not perfectly identical with the radiation patterns at ZX-plane having larger side lobes than these at YZ-plane. This is due to the asymmetric overall structure of the antenna due to the existence of the feeding lines at its sides which are situated only along the ZX-plane.

IV. CONCLUSION

A novel differentially driven circularly polarized (CP) planar aperture antenna with simple structure, wideband and high gain has been presented. The proposed design is compatible with standard planar circuit topology and can be realized on a single layer laminate for low cost and low profile. The differential feeding technique adopted in this antenna makes the integration with differential millimeter-wave (mmWave) circuits more direct. These many features make the proposed suitable for various mmWave applications.

The special shaped patch-aperture combination enables the antenna to generate CP radiation as well as attain high gain. This is due to the resultant uniform field aperture distribution within the large physical aperture of the antenna and using a cavity of about one quarter-wavelength height. In addition, the use of traveling wave excitation and differential feeding enables the antenna to achieve a stable wide operation bandwidth with good polarization purity. Simulation results of the proposed antenna show a -10dB impedance bandwidth of 17% (57-66.5 GHz), 3-dB AR bandwidth of 17.4% (56.8-67.5 GHz), and 3-dB LHCP gain bandwidth of 18% (56.3 to 67.4 GHz) with a peak gain of 14.2 dBi.

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