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A Circularly Polarized Antenna in D-Band

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Abstract—In this paper a 140 GHz circularly polarized antenna is studied. The motivation of this work is to propose a suitable antenna configuration to reduce the subsequent manufacturing cost and complexity. The resultant antenna consists of a circular waveguide feed and a dielectric cover which is used to increase antenna directivity. Numerical study shows that the proposed antenna exhibits a 17% relative S_{11} bandwidth with a maximum gain of 16 dBi. The axial ratio is less than 3 dB ranging from 130 GHz to 155 GHz.

Index Terms—Ceramics, Fabry Perot resonators, additive manufacturing, circular polarization, waveguide, D-band.

I. INTRODUCTION

Constant demand to improve wireless system performance results in a need for more spectrum. The emergence of millimetre-wave (mmW) technology as part of the 5G revolution is a real-world example as the mmW bands up to 300 GHz are capable of supporting bandwidths up to 2 GHz, which is expected to be allocated for the 5G and beyond.

At present, the 70/80GHz band (E-band) is rapidly gaining popularity, as it enables huge capacity and efficiency improvements for radios access and backhaul applications over 300 meters [1]. Several devices and product generations developed for the E-band is expected to mature for large-scale use during the 2020 to 2030 period. Further efforts are now underway to enable the use of frequencies beyond 100GHz, especially D-band (110 to 170 GHz) because there are more continuous wide bands with moderate atmospheric absorption. It is anticipated that in D-band fixed wireless service systems, a data rate of higher than 10 Gbit/s can be achieved provided that some technical impairments, i.e., transmitter noise, signal distortion, are eliminated to maximize modulation for extremely wide channels [2]. Despite the opportunities brought by the mmW bands, D-band transceivers are facing challenges in terms of transmitted power, packaging, and interconnect. The current trend is towards the use of silicon technologies to achieve high integration and low-cost transceiver modules. For these mmW modules, antennas are preferred to be integrated and

required to be compatible with the silicon process. On-chip antennas are preferred but it is challenging to design high efficiency high gain antennas within a small chip area [3], [4]. Antenna in Package (AiP) or antenna on Package (AoP) has emerged as a cost-effective solution as the antenna is off-chip and implemented on low-cost substrates [5]. However, the performance and cost of the substrate is frequency sensitive, which limits the use of AiP/AoP above 100 GHz.

It is well known that the metallic waveguide technology is well developed for applications in the mmW and terahertz ranges. Waveguide approaches are low-loss and precise thus enabling excellent interconnect with active circuits. Traditional waveguide structures are manufactured using CNC machining. The cost for small volume production/prototyping is high. In addition, when waveguide antennas are used as the radiating element, its geometry are limited by the capability of the tools of the CNC machines. It is desired a flexible and on-demand manufacturing method is employed to achieve faster turnaround and lower cost. Additive manufacturing (AM) is a promising solution and gaining more and more interest in antenna manufacture above mmW frequencies [5]–[8]. The state-of-the-art AM technologies not only can produce precise all-metal structures but also all-dielectric objects with even a high relative dielectric constant [9], [10]. Therefore, it is possible to realize high-performance antennas with complex geometries at frequencies above 100 GHz. In this study we present a hybrid 3D printed antenna which is circularly polarized operating at the 140 GHz band. Circularly polarized (CP) mmW antennas can be used in a wide variety of potential applications such as biomedical imaging and the use of CP antenna can reduce the polarization mismatching loss of wireless communication systems. D-band CP antennas are less investigated to date because of the challenges in antenna manufacturing. Here a Fabry Perot configuration [11], [12] is employed to achieve gain enhancement over a CP waveguide feed. The antenna parts are compatible with metal and dielectric 3D printing and the resultant antenna

is compatible with front ends with standard waveguide interface at D band.

II. WAVEGUIDE FEED

To design the CP antenna at D-band by leveraging the capabilities of additive manufacturing technologies, the Fabry-Perot cavity is considered in our design as the superstrate and feed can be printed separately. Fig. 1 shows the perspective view of the proposed antenna which consists of a dielectric cover as the superstrate and the waveguide feed as the CP source. For ease of measurement, the holes are made through each layer to connect to a standard WR6 waveguide flange. The low directivity of the metallic waveguide feed can be enhanced by placing the dielectric cover over the feed while maintaining a satisfactory CP performance. In the next section we will show the design process of the antenna.

Fig. 1. Configuration of the antenna

The key component for realizing circular polarization of the antenna is the feed with polarization conversion function [13]. The presented polarizer can act as the feed to transmit CP waves and it is suitable to be fabricated using AM. Fig. 2 depicts the schematic view of the feed. For clarity, only the air-filled part of the metal polarizer is shown. The CP is formed at the output of the circular waveguide by introducing a quarter-wave groove cut in the waveguide inner wall when the input port is excited with a linearly polarized wave.

Fig. 2. Schematic view of the air-filled part of metal polarizer

The operating principle of the polarizer is that linearly polarized incident TE₁₁ modes are applied $\pm 45^\circ$ offset with respect to the groove so that the decomposed modes undergo different phase shifts through the groove. After propagating along the polarizer, the amplitudes of the two modes are approximately equal and their phase differ by 90 degrees thereby emanating right/left-hand circularly polarized wave. The simulated reflection coefficient and axial ratio are shown in Fig. 3. The -10 dB S_{11} bandwidth ranges from 130 GHz to 155 GHz and the AR is less than 3 dB across the band. Thanks to the symmetrical radiating aperture, the radiation patterns of the two principle far-field planes at 140 GHz are almost identical with a realized gain of 7 dB, as shown in Fig. 4. Moreover, a wide AR bandwidth can be observed at both planes, i.e., $\pm 60^\circ$ for $AR \leq 3$ dB.

Fig. 3. Simulated reflection coefficient and axial ratio

Fig. 4. Simulated radiation patterns at two principle planes at 140 GHz

III. ANTENNA DESIGN

The CP radiation of the final antenna is achieved by implementing a high permittivity material cover as a planar partially reflecting surface in front of the CP source. With multiple reflections of the wave inside the formed dielectric-air-metal structure, maximum radiation at broadside direction occurs when the PRS (dielectric layer) has an optimum thickness that yields to in-phase transmitted wave. A dielectric constant of 10.2 is chosen to yield a moderate antenna gain. Also, the whole dielectric cover is designed to be printed using lithography-based ceramic manufacturing technology.

Fig. 5. Side view of the conceptual antenna configuration

Fig. 6. Simulated gain patterns with/without the dielectric cover at 140 GHz

In addition to the thickness of the dielectric cover, the distance between the dielectric and the ground plane should also be optimized with an empirical value of half wavelength at the operating frequency. Fig. 6 shows the simulated gains of the antenna with/without the dielectric cover. It is found that by employing the PRS dielectric layer, the antenna gain can be increased by 8.5 dB. The

beam pattern is narrowed due to the gain increase and the side lobe level is excellent, around 20 dB.

The final step is to design an impedance matching layer (IML) for reducing the mismatch between the dielectric cover and the feed. Fig. 7 shows the IML using a stepped circular waveguide transition. The transition has a diameter of ds and the height is hs . Table I lists all the parameters of the optimized antenna. It can be noted from Fig. 8 that there is a maximum gain increase of 8.5 dB at 145 GHz thanks to the introduction of the PRS dielectric cover. More importantly, the presence of the cover has no impact on the AR of the antenna. The simulated 3D radiation pattern at 145 GHz is shown in Fig. 9.

Fig. 7. Schematic view of the impedance matching layer design

TABLE I
GEOMETRIC PARAMETERS OF THE ANTENNA (DIMENSION: MM)

gl	gw	df	ts
2.3	0.53	0.51	0.17
ϵ_r	h	ds	hs
10.2	1	2.6	0.2

Fig. 8. Simulated gain and AR of the resultant antenna (dotted line: gain of waveguide feed only)

Fig. 9. Simulated 3D radiation pattern at 145 GHz

IV. CONCLUSION

In this work, the Fabry Perot resonant antenna principle is exploited to design a 140 GHz circularly polarized antenna with a directive beam. To be compatible with the current 3D printing techniques, the antenna feed and gain enhancement superstrate are chosen to be metallic and dielectric, respectively. The dielectric cover placed above the feed is shown to be able to increase the gain by 8.5 dB. The resulting antenna is expected to be printed by Direct Metal Laser Sintering (DMLS) and Stereolithography (SLA) process.

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