Compact Antennas in Ridge Gap Waveguide with Circular Polarization

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***Abstract* – In this paper, two compact antennas in Ridge Gap Waveguide (RGW) technology, working at 60 GHz, with a high-purity circular polarization (CP) within a broad bandwidth are manufactured and measured. The antennas are fed from the bottom plane with a WR-15 waveguide (V-band), which couples the wave to the RGW. CP is generated in a simple and effective way, by means of two orthogonal feeder arms that excite a CP in a diamond-shaped slot on top. A broadband matching with reflection coefficient magnitude below −10 dB ($S_{11} < -10$ dB) is achieved from approximately 60.3 to 69.6 GHz (> 9 GHz). Applying the axial ratio criterion (AR < 3dB) the bandwidth in CP is 14.48%, with respect to the central frequency (59 to 70 GHz). The maximum gain in both designs is obtained at 67 GHz, with a value of 5.49 and 11.12 dB respectively.**

I. INTRODUCTION

The gradual saturation of the lower part of the radio spectrum has spurred research towards efficient antennas and feeding methods in higher bands, mainly millimeter and terahertz waves. Nevertheless, a fundamental obstacle that must be circumvented to achieve a full development of high frequency technology is the problem of guiding waves with low loss.

Using different feeding techniques can be a solution that, in combination with an appropriate fabrication method could alleviate loss. In recent years, Gap Waveguide (GW) technology (developed from the beginning by Prof. Per-Simon Kildal) has gained a lot of interest since it is a reliable and competitive alternative for high-frequency communications. Three main variants have been developed: Groove Gap Waveguide (GGW) [1], Ridge Gap Waveguide (RGW) [2] and Microstrip Gap Waveguide (MGW) [3]. GW shows considerable improvements, such as low loss, it does not require electric contact and it is easily adaptable to flat surfaces [4]. It also has a lower manufacturing cost with respect to traditional hollow waveguides, since the tolerances are coarser alleviating the fabrication constraints.

It is evident that minimizing path loss is very important. Circular polarization (CP) in wireless communications systems has several advantages over linear polarization: CP does not require polarization alignment between the transmitter and the receiver and is more robust against multipath effects [5]. Several examples in the literature use GW technologies to generate CP. In [6], an antenna with CP based on an array of rotated rectangular slots was designed in the band of 75-80 GHz.

II. ANTENNA CONFIGURATION AND DESIGN

All the antennas in this paper were designed and optimized to operate in the V-band of millimeter-waves, specifically from 55 to 70 GHz, using the Transient Solver of the commercial simulator CST Microwave Studio®. Photographs of the fabricated prototypes are shown in Fig. 1. The material employed in all the structures is aluminum, due to its good conductivity in the operation band ($\sigma_{Al} = 3.72\times10^{6}$ S/m), mechanical robustness and compatibility with standard manufacturing techniques. In addition, the antennas were manufactured using Standard Computer Numerical Control (CNC) milling machine method.

The structure is fed from the bottom by means of a standard WR-15 waveguide to make it compatible with standard measurement systems based on vector network analyzers. Fig. 1(a) shows the WR-15 waveguide connection from the bottom. Fig. 1(b) shows the WR-15 to RGW transition used to couple the wave to the RGW.

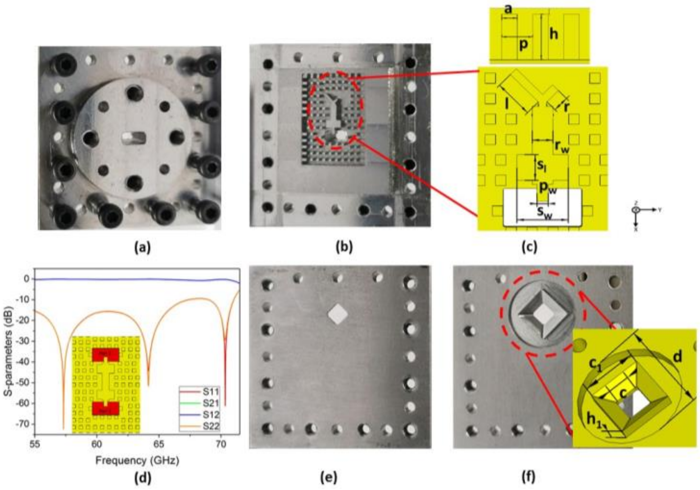

TABLE I
DESIGN PARAMETERS

Parameter	*Description*	*Values (mm/λ_0^*)*
l	Left Arm Length	1.77 / 0.38
r	Right Arm Length	0.64 / 0.14
r_w	Ridge Width	1.0 / 0.21
p_w	First Step Width	0.54 / 0.11
s_w	Third Step Width	2.45 / 0.52
s_l	Third Step Length	1.05 / 0.22
a	Pin Width	0.5 / 0.10
p	Pin Period	1.0 / 0.21
h	Pin Height	1.5 / 0.32
d	Groove Diameter	10.93 / 2.31
c	Diamond Length 1	2.65 / 0.56
c_1	Diamond Length 2	5.61 / 1.19

$^*\lambda_0$ = 4.72 mm at 63.5 GHz

Fig. 1. Photographs showing a view of: (a) Bottom WR-15 waveguide flange; (b) feeding system. (c) Schematic of the antennas feeding, top view. (d) Simulated reflection and transmission coefficients of feeding system using a back-to-back evaluation (inset: schematic with the configuration). Photographs showing the top plate of the (e) D antenna and (f) DHG antenna (inset: detail of the main radiator with dimensions).

It consists of a simple stepped impedance matching network composed of two main subsections (see Fig. 1(c) and Table I for dimensions). As shown in Fig. 1(d) and inset, the transition has a good matching within the considered band, with a reflection coefficient below −10 dB and negligible insertion loss.

Two top plates were manufactured, each of them with a specific objective. The basic design is shown in Fig. 1(e). It is a diamond-shape (D) slot antenna put on top of the feeding network plate. In addition, a circular groove concentric with the diamond slot is inserted for improving the gain of the antenna, Fig. 1(f) and inset. This last design is called diamond-horn-groove (DHG) antenna.

To generate the CP, the feeding ridge is finished in two orthogonal arms of different lengths. From the dimensions shown in Table I, it can be observed that the length difference corresponds approximately to $\lambda_0/4$. This guarantees that the phase difference between both arms is close to 90º, as demonstrated in Fig. 2(a), which shows that the electric field distribution in both arms is in quadrature: the maximum value in one arm corresponds to nearly zero in the other. The surface current excited on the upper plate has a clear spiral pattern, as shown in Fig. 2(b) and (c), indicating that the antenna supports right-handed CP (RHCP).

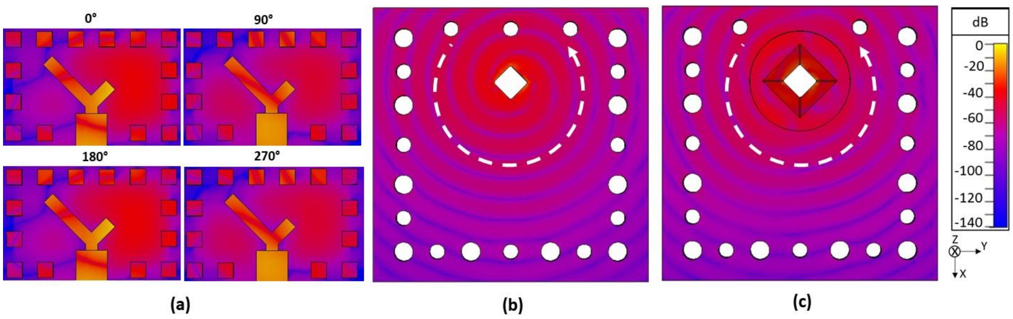

Fig. 2. (a) Electric field magnitude at 63.5 GHz at four different snapshots, showing that the ending arms are operating in quadrature. Top view of the surface current on the top plate at 63.5 GHz. (b) D antenna. (c) DHG antenna.

III. EXPERIMENTAL RESULTS

The measurements were performed in an anechoic chamber. A PNA network analyzer E8361C (Agilent Technologies) was used in the frequency range from 59 to 70 GHz and the frequency span was discretized with steps of 50 MHz. The radiation patterns were measured by placing a transmitting horn antenna with linear polarization (Mi-Wave 261) at a distance of 1500 mm (the farfield distance at the operation frequency is 720 mm) from the antennas under test (AUTs). In each of these positions, the AUT was swept in elevation from –90° to 90° with a step of 0.5°. As the test antenna (Mi-Wave 261) has linear polarization, in each measurement it was rotated in plane at orthogonal positions and from the recorded curves, the CP characteristics of the AUT were obtained.

Fig. 3 shows measurement results for both antennas. Their performance was evaluated in terms of the reflection coefficient, broadside gain, axial ratio (AR) and polarization purity. Analyzing the experimental results, we note that the reflection coefficient in both cases have good impedance matching, below −10 dB from 60.5 to 69.3 GHz, Fig. 3(a) and (b) red curve. As shown in Fig. 3(a) and (b) blue curve, the gain peak of the DHG antenna is 11.12 dB at 67 GHz in measurement. Compared with the D antenna, this evolved design meets the intended objective. Applying the criterion of AR < 3 dB, we find that the D and DHG antennas have a good CP BW, see green curve. The experimental radiation patterns of both antennas are shown in Fig. 3(c) and (d). The D and DHG antennas, present more than 15 dB of cross polarization isolation, corroborating that the antenna polarization is RHCP. In addition, this last variant shows a clearer main lobe pointing at broadside in the radiation diagram, accounting for a larger directivity with respect to the basic D antenna, confirming the simulation results.

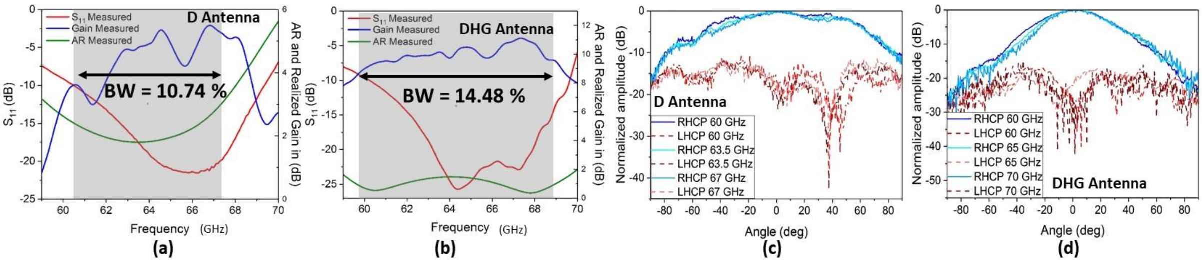

Fig. 3. Measurement results of the two designed antennas, reflection coefficient magnitude (red curve), realized gain at broadside φ = 0° and θ = 0° (blue curve) and axial ratio (green curve). (a) D antenna. (b) DHG antenna. Co-polar and cross-polar measured radiation patterns at several selected frequencies. (c) D Antenna φ = 0º, *y-z* plane. (d) DHG Antenna φ = 0º, *y-z* plane.

IV. Conclusion

To sum up, in this paper we have designed and manufactured two antennas with CP operating in the V-band based on RGW technology. We have demonstrated that the use of two arms of different lengths in the feeding system allows the generation of CP in a simple way. The resulting antennas are small and very compact with excellent radiation characteristics. A broad operation BW of 14.48% (60.3-69.6 GHz) with an AR < 3 dB is obtained by DHG antenna. It achieves a maximum gain of 11.12 dB, a high value considering its small footprint (30 mm × 30 mm) and simplicity. Both manufactured antennas have RHCP with more than 15 dB of cross polarization isolation.

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