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# High-Gain Luneburg Lens on COC Substrate for 300-GHz Applications

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**Abstract**—A Luneburg lens quasi-optical beam-former is used to excite a leaky-wave antenna at 275 GHz. Both the lens and the antenna are fabricated on a Cyclic Olefin Copolymer (COC) substrate. The full system is etched on the polymer by photolithography. Numerical results show a reflection coefficient lower than  $-24$  dB and a gain higher than 21 dBi over a 40% fractional bandwidth, spanning from 220 GHz to 330 GHz. The efficiency of the antenna is estimated to be 28% at the center frequency (275 GHz).

**Keywords**—Luneburg lens, leaky-wave antennas, Cyclic Olefin Copolymer, photolithography, polymers, beam steering.

## I. INTRODUCTION

Technological advances in the sub-millimeter wave regime (from 100 GHz up to 10 THz) are pushing the development of radio frequency front-ends in this frequency range [1]-[2]. Such front-ends can provide bandwidths that are broad enough to support data rates beyond 100 Gb/s [3].

Different fabrication technologies have been thoroughly investigated in the literature to face the challenges (such as material losses and fabrication tolerance) arising in the sub-millimeter wave range. Deep Reactive Ion etching, micromachining processes, and diffusion bonding can enable vacuum guiding and radiating structures reducing the overall system losses [4]-[7]. However, the advantages of such fabrication technologies come with high cost and complexity. In [8]-[9], Benzocyclobutene (BCB) polymer was used as substrate to fabricate a single-layer antenna operating at 300 GHz. The design was simple, but it had relatively high losses due to the small thickness of the spin-coated BCB (only 30  $\mu\text{m}$ ) and its high dielectric losses. Besides, the metallized vias used for the constrained lenses added complexity to the fabrication. This work addresses the above-mentioned problems. First, a high gain Luneburg lens is used as quasi-optical beamformer at sub-millimeter waves. Then, the plane wave generated by the flat Luneburg lens illuminates a leaky-wave antenna (LWA) array, which constitutes the radiation aperture. The full system is built on COC with a loss tangent that is around one order of magnitude lower than that of BCB. Moreover, the system is built without any metallized vias to simplify the fabrication process.

The paper is organized as follows. The lens, its excitation and the LWA radiating part are discussed in Section II, and the numerical results are presented in Section III. Conclusions are drawn in Section IV.

## II. ANTENNA CONFIGURATION

The full structure is shown in Fig. 1. The substrate used is COC commercially known as Topas 8007 ( $\epsilon_r = 2.35$ ,  $\tan \delta = 0.002$  at 300 GHz [10]) and has a thickness of 140  $\mu\text{m}$ . Gold is used for the metallic layers with conductivity equal to  $\sigma = 20 \times 10^6 \text{ S/m}$  at 300 GHz [6].

The antenna can be divided in three main blocks. The first one is a feeder that generates the cylindrical wavefront used to illuminate the lens. This input part is an exponentially tapered transmission line. The feeder's edge tapering can be retrieved by optimizing the length of the feeder and its exponential factor. The final design parameters provide an edge tapering of  $-13$  dB for a lens with a 10 mm diameter or  $14 \lambda_g$  where  $\lambda_g$  the guided wavelength inside the substrate at 275 GHz is. In turn, the distance between the center of the lens and the phase center of the feeder is 10.3 mm ( $14.5 \lambda_g$ ). In practice, this feeder will be excited by a transition from WR-3 waveguide or GSG probe.

The second element in the antenna system is a Luneburg lens, which converts the cylindrical wavefront into a plane wave suitable to excite the radiating aperture. The Luneburg lens consists of a grid of sub-wavelength unit cells each designed by sinusoidally-modulated microstrip transmission lines. The length and/or the width of the lines are used to implement the permittivity profile required for the Luneburg lens [11].

The last block corresponds to the radiating aperture, and it consists in a periodic LWA which provide frequency steering. The LWA comprises 24 rows of slots along  $y$  with each row having 58 slots along  $x$ , as shown in Fig. 1.

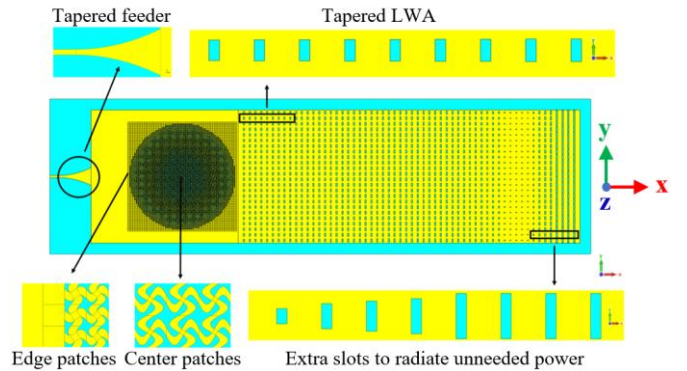


Fig. 1. Top view of the full antenna system.

## III. NUMERICAL RESULTS

The full system has been simulated using CST MWS [12]. The reflection coefficient of the antenna is shown in Fig. 2. The antenna shows a fractional bandwidth of more than 40% for a reflection coefficient lower than  $-24$  dB from 220 GHz to 330 GHz. The radiation patterns in E-plane ( $z$ - $x$ -plane in Fig. 1) are shown in Fig. 3. A scanning range from  $-76^\circ$  to  $-3^\circ$  in elevation is obtained. The corresponding radiation patterns in H-plane are not shown here for the sake of brevity, but they provide a SLL lower than  $-20$  dB in the full band. The gain is larger than 21 dBi across the whole band with a

maximum of 26 dBi at 280 GHz. Simulations show losses of 5.6 dB at the center frequency due to dielectric and the conductor losses of the system.

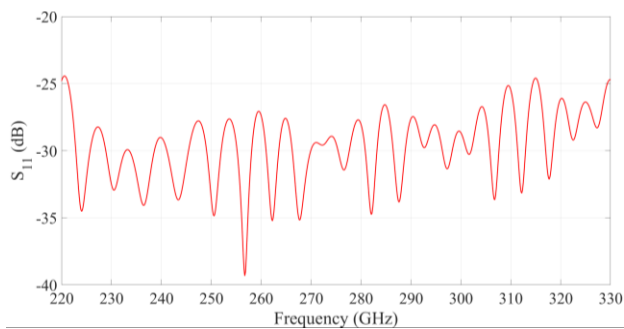


Fig. 2. Simulated magnitude of the reflection coefficient at the input port.

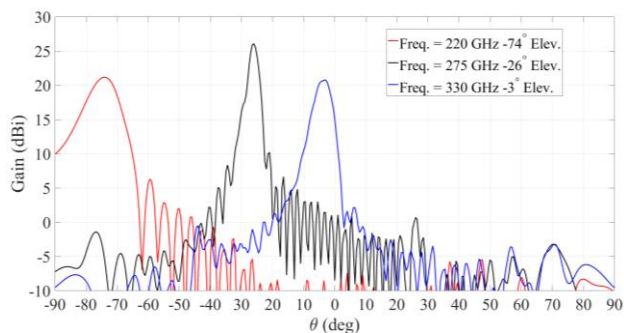


Fig. 3. Simulated radiation patterns in E-plane (xz-plane in Fig. 1). The pointing directions for each beam are provided in the legend.

#### IV. CONCLUSIONS

A full antenna system operating in the sub-millimeter frequency band from 220 GHz to 330 GHz is presented. The antenna consists of a Luneburg lens feeding an array of slots operating as a leaky-wave antenna. The antenna is tapered to maximize its gain. The maximum gain is 26 dBi at 280 GHz. The radiation efficiency of the antenna is estimated to be between 20 – 40% depending on the frequency due to dielectric and conductor losses. A prototype has been fabricated and measurement results will be presented at the conference.

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