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Flat Lens Antenna using Gap Waveguide Technology at Millimeter Waves

Dayan Pérez-Quintana [1], **Christos Bilitos** [2], **J. Ruiz-García** [2], **D. Gonzalez-Ovejero** [2], **Miguel Beruete** [1]

[1] Department of Electrical, Electronic and Communications Engineering, Public University of Navarra, Campus Arrosadia, 31006 Pamplona-Iruña.
[2] Univ. Rennes, CNRS, IETR (Institut d'Électronique et de Télécommunications de Rennes) - UMR 6164, F-35000, Rennes, France
dayan.perez@unavarra.es

***Abstract* – In this paper, a flat lens antenna using Gap Waveguide (GW) technology working in the millimeter waves band was designed. The metamaterial lens is fed using a Groove Gap Waveguide (GGW) horn antenna in order to achieve a plane wavefront at broadside. Both devices, metalens and GGW antenna achieve excellent radiation results when combined together. Due to metallic composition, the structure presents more robustness, low loss, and adaptability to a flat surface, able to be used in millimeter wave application.**

I. INTRODUCTION

With the rapid development of modern wireless communication technology, the fifth-generation (5G) mobile standard and Internet of Things (IoT), the 60 GHz frequency band has received a special attention due to its potential functional benefits. The demand for faster speed, the greater volume of information required and multi-beam antennas with high gain, have gained increasing attention from the engineering community to solve all of these modern problems.

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. Traditional feeding systems like waveguides and microstrip lines suffer from increasing loss as the frequency grows. In last decade, Gap Waveguide (GW) technology has gained a lot of interest since it is a reliable and competitive alternative for high-frequency communications [1] with three main variants: groove-gap waveguide (GGW) [2], ridge-gap waveguide (RGW) [3] and microstrip-gap waveguide (MGW) [4]. GW shows considerable improvements compared to standard metallic waveguides, such as low loss, it does not require electric contact and it is easily adaptable to flat surfaces [5]. It also has a lower manufacturing cost with respect to traditional hollow waveguides, since the tolerances are coarser alleviating the fabrication constraints.

Beyond that, it is evident that designing a high gain and broadband antenna using this technology opens new avenues for high frequency communication. There is an increasing interest in MTS antennas due to their ability to provide high gains, while at the same time maintaining a light weight and a low profile, making them excellent candidates for lens antenna applications such as the Luneburg Graded Index (GRIN) lens [6]. In order to improve the antenna characteristics, a very attractive idea is to use classic antennas in GW technology and combine it with the metalenses. Therefore, the main objective of this investigation is to combine these technologies to have antennas with good radiation characteristics and support the implementation of 5G mobile communications.

II. DESIGN OF THE LENS

Typically, metasurfaces consist of sub wavelength patches or metallic elements arranged in a regular lattice arrangement [5]. By loading a Parallel Plate Waveguide (PPW) with a fakir's bed of nails consisting of metallic posts of different height, we can emulate the behavior of an artificial dielectric for a TM surface wave [7]. Here, a metal-only metasurface antenna is implemented in order to overcome the dielectric losses associated with typical lens antennas in the microwave band, as well as provide integrity to the antenna in harsh environmental conditions.

Realizing this concept, a planar Luneburg lens is considered as it offers full azimuthal scan with fan beams in the V-band taking even more advantage of the all-metal lens properties. The refractive index of a Luneburg lens follows the next equation:

$$n = \sqrt{2 - \left(\frac{r}{R}\right)^2} \tag{1}$$

Where r is the distance between the point of interest and the center of the lens, and R is the radius. Simulating the dispersion diagram of the unit-cell, as shown in Fig. 1(a), we can see the formation of a stop band, which in turn shows single mode propagation with a linear, non-dispersive behavior in a large bandwidth within the considered frequency range, making this unit-cell a suitable candidate for the realization of the lens. The parameters are the periodicity p_{uc} of the unit-cell, the width of the metallic post a_{uc}, and the ground height h_{ground}. By varying the ground height where the post lays, thus varying the effective height of the post we are able to derive an effective refractive index at single frequency (Fig. 1(b)).

Matching that to the profile on the Luneburg lens and mapping the corresponding ground height of each unit-cell, we can construct the final geometry of the metasurface lens with radius equal to $5\lambda_0$ and the PPW height being $d = 2.1$ mm above the maximum metallic post height ($h_{uc,max} = 1.3$mm) where λ_0 is the freespace wavelength at the design frequency $f_0 = 60$ GHz. The lens system is first fed with a conventional H-plane sectoral horn giving satisfactory results, Fig 1(c).

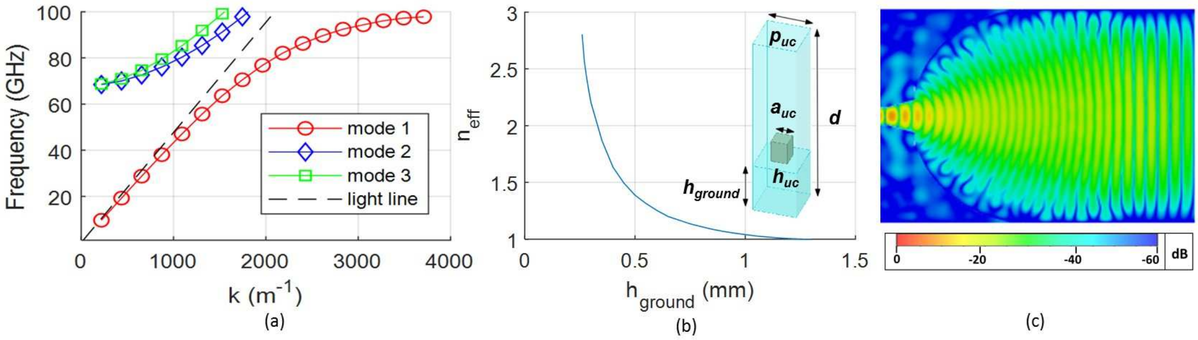
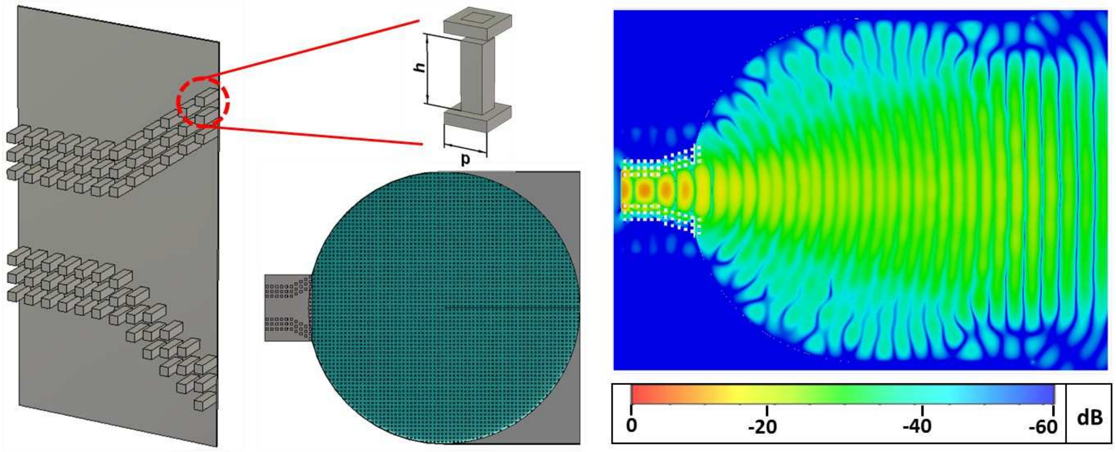


Fig. 1. (a) Dispersion diagram of the unit cell for the following dimensions: $p_{uc} = 0.8$mm, $a_{uc} = 0.3$ mm and $h_{ground} = 0.75$mm. (b) Equivalent refractive index as a function of the unit cell's ground height h_{ground} at $f_0 = 60$ GHz. (c) Normalized electric field magnitude $|\mathrm{Re}\{E_z\}|$ at 60 GHz for the planar PPW Luneburg lens of radius $R = 5\lambda_0$ fed with an H-plane sectoral horn.

III. ANTENNA DESIGN

Up to this point, we have modulated a surface using a bed of nails to achieve the Luneburg lens behavior and have excited it with a classical metallic horn. The next step is to feed the Luneburg lens with a horn antenna made in GGW technology.

The first step is to design a horn antenna using GGW technology able to obtain a similar phase center than the classical horn used before. Applying the theory studied in [1], Fig. 2(a) shows the GGW horn antenna used to feed the metalens. In this case, a single pin (inset of Fig. 2(a)) of height h=1.5 mm and periodicity p=1 mm generates a bandgap around 40-80 GHz. This frequency band is adequate for our design. In this case, the main objective is to achieve a similar phase center than the classical horn antenna to feed the Luneburg lens. Fig. 2(b) shows the GGW horn antenna placed on the metasurface edge, in order to obtain similar radiation characteristics as before. Finally, Fig. 2(c) shows the normalized vertical component of the electric field from a top view. Analyzing it, it is clear that we achieve a plane wave in the broadside direction, in good agreement with the previous results using a conventional H-plane sectoral horn. It is clearly seen that the lens manages and transforms the wavefront from the GGW horn antenna into a plane wave. This time, the GGW horn antenna used gives similar radiation characteristic that in combination with a Luneburg lens improves the results in a more compact design.



(a) (b) (c)

Fig. 2. (a) GGW Horn Antenna. (b) Luneburg lens plus GGW horn antenna. (c) Normalized electric field magnitude $|\mathrm{Re}\{E_z\}|$ at 58 GHz in decibel scale.

VI. CONCLUSIONS

To sum, in this article an analysis of a Luneburg lens excited by a GW horn antenna has been presented. A metamaterial lens has been synthesized using metallic pins to modulate a specific permittivity in order to achieve a plane wave at broadside direction. A GGW horn antenna was designed, that combined with the metasurface achieved excellent radiation characteristic. Furthermore, thanks to its fully metallic structure and design, this system has more robustness, low loss and adaptability to plane surfaces; i.e., necessary features for millimeters applications.

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