A Ka-band glide-symmetric planar Luneburg lens with combined dielectric/metasurface for 5G communications

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Abstract – Here, we propose a cost-effective metasurface lens solution based on the use of metallic glide-symmetric unit cell combined with a dielectric sheet. Our solution reduces significantly the manufacturing and assembly complexity of previously investigated Ka-band Luneburg lens implemented in glide symmetry technology. The required refractive index for this unit cell has been studied for the geometrical parameters, and an efficient transition between different media in the parallel plate configuration of the lens is also investigated.

Index Terms — glide symmetry; periodic structures; Luneburg lens; metasurface; dielectric; transition; 5G.

1. Introduction

The rapid increase in demand of wireless communication services and the huge development of mobile terminals has lead to a need of higher data rates that involves an increase in the operating frequency band. Millimeter-wave frequencies are under discussion to be applied in 5G and the 28 GHz-band has already been specified in 3GPP for the implementation of 5G networks [1] in some countries. 5G systems will include multibeam, highly directive and steerable antennas as key components. Therefore, lens antennas are promising candidates for use in 5G radio systems since they are wideband and directive. However, typical dielectric lenses are bulky and exhibit high losses. These disadvantages can be mitigated with the use of fully metallic metasurfaces for the lens design [2].

Recently, the electromagnetic properties of glide symmetry technology [3], [4] have shown potential on the realization of 2-D, low loss, compact and ultrawideband metasurface lenses [5], [6]. The first fully metallic Ka-band glide-symmetric Luneburg lens was presented in [6] with 28 GHz as center frequency and 20% bandwidth. This prototype uses a unit cell based on pin-loaded holes organized in a glide-symmetric configuration to modulate the required effective refractive index ($n_{eff}$). Even though the lens results were very satisfactory in terms of port isolation, radiation performance and loss, there were discrepancies on the measured return loss due to assembly tolerances concerning the needed air gap between the two parallel metal plates where the glide-symmetric holes were placed. Furthermore, the unit cell employed in [6] requires loading the hole with a square pin in order to reach a value $n_{eff} = 1.414$ at the center of the lens, which is a requirement in Luneburg lenses [7]. The pin-loaded holes increased the manufacturing complexity since accurate milling technique was needed for fabrication.

In this work, we present a modification on the previous unit cell and its numerical analysis, achieving a significant simplification of the lens fabrication and assembly ensuring less sensitivity to tolerances, reducing the cost and facilitating mass production.

2. Unit cell investigation

Using a cylindrical hole as glide-symmetric unit cell, i.e. containing two off-shifted layers separated by an air gap, where we control $n_{eff}$ with the hole height keeping the other design parameters fixed, involves that we can drill holes in a metal plate simplifying the fabrication of the lens with respect to the solution presented in [6]. However, the values of $n_{eff}$ for a single hole configuration do not reach 1.414 unless we reduce the gap dramatically (around 75 µm) which would complicate the assembly. Here, we suggest filling the air gap of a certain area around the center of the lens with a dielectric disk to increase the refractive index and achieve the required values. This unit cell solution is illustrated in Fig. 1, as well as its corresponding dispersion diagram where the values of $n_{eff}$ cover the required range by varying the hole height $h_2$. The additional advantage of using this unit cell type is that we provide mechanical support between the two metal plates, so that the gap is kept fixed avoiding possible misalignments that we experienced in [6] and that affected the return loss performance. The dispersion diagram in Fig. 1 also shows that there is no need to fill the whole lens area with dielectric since we can reach a refractive index of up to around 1.29 with just a holey unit cell with air gap (no presence of dielectric) equal to 0.1 mm and with acceptable dispersion for our band of interest (25.2-30.8 GHz). Therefore, we only use a dielectric disk for the region where we need to achieve values of $n_{eff}$ from 1.29 to 1.414. Both unit cells in Fig. 1 have as common parameters: period $p$ = 3.2 mm and radius $r$ = 1.36 mm. The air gap $g$ is 0.1 mm and the substrate thickness of Rogers RT/duroid 5880 (permittivity $\varepsilon_r$ = 2.2 and loss tangent $\tan\delta$ = 0.0009) is $g^2$ = 0.127 mm.
3. Transition design and simulation results

Since the fields propagate in a parallel plate configuration through two different media, a suitable transition is needed to ensure a smooth matching of $n_{ef}$ between the region with dielectric and the region with air. A transition has been investigated by considering the waveguide configuration illustrated in Fig. 2. This structure consists of holey unit cells with the gap filled with air on one side and holey unit cells with the gap filled with dielectric on the other side connected by a section that contains several matching holes with optimized height to provide a smooth transition of $n_{ef}$ between the different media. The two longer sections step up and down $n_{ef}$ to a value of 1.29. We should point out that the incoming wave in this configuration can have any angle. Thereby, normal incidence was emulated by simulating the transition in a waveguide with Perfect Magnetic Conductor (PMC) side walls; while for oblique incidence, a waveguide with Perfect Electric Conductor (PEC) side walls was used. Since the dielectric disk covers the holes differently, two straight cuts along x- and y-axis and +/-45° away were optimized for both cases. Fig. 3a shows the matching sections on the complete glide-symmetric Luneburg lens that contains a total of 878 unit cells in each metal layer, whereas Fig. 3b and Fig. 3c depict the optimized holes of the matching sections for the cuts along x- and y-axis and +/-45°. The $|S_{11}|$ parameter of the designed transitions was simulated with CST Microwave Studio and the results for normal and oblique incidence for the x- and y-axis and +/-45° transitions are presented in Fig. 4a. Fig. 4b shows the plane wave generated on one side of the holey glide-symmetric lens when we excite using a discrete port at the opposite side.

4. Conclusions

A Ka-band glide-symmetric Luneburg lens with manufacturing and assembly flexibility has been proposed. The holey unit cells can be easily realized by simple drilling, and possible gap misalignments are avoided by filling the gap with a substrate disk occupying 55% of the lens area.

References