Hyperbolic Lens Antenna in Groove Gap Waveguide Technology at Sub-millimeter waves

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Abstract— **In this paper, a flat hyperbolic lens antenna using Groove Gap Waveguide (GGW) technology is designed at 300 GHz. A GGW horn antenna is used to feed the metamaterial lens placed in a parallel plate waveguide (PPW), in order to increase the directivity in the direction of propagation. The combination of both devices, the metalens and the GGW antenna, achieves excellent radiation performance.**

I. Introduction

Terahertz (THz) technology has recently attracted significant research interest due to the wide available bandwidth and a short wavelength that provides high resolution with modest apertures. Hence, among the most popular applications one finds high-resolution radars, imaging systems, sensing, security screening, and high-speed communications [1].

Gap waveguide (GW) technology has been studied extensively in the last decade [2]. Some investigations in the sub-millimeter range present good results in different applications [3], [4]. The ability to integrate the GW technology with a flat lens has already been demonstrated [5]. By varying the pin height, it is possible to derive an effective refractive index, a feature that can be exploited to devise graded-index devices such as a Luneburg lens, for example.

In this work, a hyperbolic lens using GW technology at 300 GHz is designed. A Groove Gap Waveguide (GGW) horn antenna is used to feed the metamaterial lens in order to achieve a plane wavefront in the direction of propagation. The metamaterial lens implemented follows a classical hyperbolic profile, and consists of a bed of nails with the same height to get a homogenous refractive index. Both devices, the metalens and the GGW antenna achieve excellent radiation results when combined together.

II. Design and simulations results

Typically, metasurfaces consist of subwavelength patches or slots arranged in a regular lattice [6]. By loading a Parallel Plate Waveguide (PPW) with a fakir's bed of nails consisting of metallic posts with periodicity much smaller than the wavelength, control on TM surface wave propagation can be achieved giving rise to an artificial structure with an homogenized effective permittivity. The advantage of using classical lens shapes such as hyperbolic and elliptical profiles is mainly that they have the same permittivity in the entire structure and therefore there is no need of modulating it spatially, unlike gradient index structures such as Luneburg lenses.

The lens shape can be expressed in polar coordinates as:

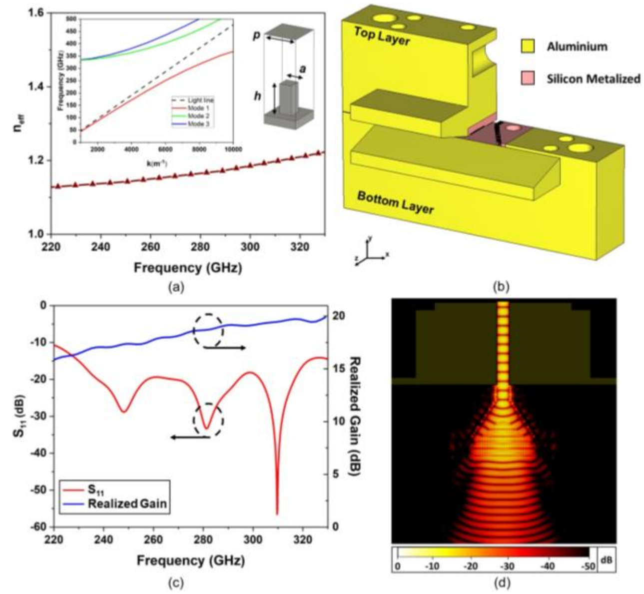

Fig. 1. (a) Equivalent refractive index of the pin. The inset shows a dispersion diagram of a metallic pin with the following dimensions: p = 0.16 mm, a = 0.06 mm and h = 0.121 mm. (b) Schematic of a Hyperbolic lens system. (c) Simulated results of the structure. Magnitude of the reflection coefficient in dB and peak realized gain vs frequency. (d) Normalized electric field magnitude |Re{Ez}| at 310 GHz in decibel scale.

$$\rho(\psi) = \frac{(n-1)F}{n \cos \psi - 1} \qquad (1)$$

where n is the refractive index, F is the focal length and ψ is the angular coordinate. In (1) n defines the profile of the curve: if $n < 1$ the lens is elliptic, and if $n > 1$ is hyperbolic [7].

With the pin parameters fixed to: height h = 0.121 mm, period p = 0.16 mm, and side a = 0.06 mm, a refractive index around 1.1 is synthesized in the operation band, see Fig 1(a). Fig. 1(a) inset shows the dispersion diagram of the unit-cell obtained with the commercial simulator CST Microwave Studio®. This diagram displays monomode propagation with a linear, almost non-dispersive behavior in a large bandwidth within the considered frequency range, which makes this unit-cell a suitable candidate for the realization of the lens.

Fig 1(b) shows the design setup: two aluminum blocks are used to host and sandwich the metallized Si wafers with the hyperbolic lens and the GGW. Each block presents a flared section to achieve a smooth air transition. The lens and GGW horn antenna layers are colored differently, because their manufacture is foreseen by means of silicon micromachining and metallization, in contrast to the encapsulation. Due to the high design frequency considered, losses in the metal parts must be carefully taken into account. In this case, the aluminum is modelled with an effective conductivity corresponding to its nominal DC conductivity divided by a factor of 6, to model imperfections such as roughness, etc. Therefore σ_{Al}=5.93×10^6 S/m. Fig. 1(c) shows the reflection coefficient (red curve) and the directivity (blue curve) vs frequency. First, we note that the antenna is matched in the entire operation band (from 220 to 330 GHz), with the criterion of having a reflection coefficient magnitude below −10 dB. The prototype has a high gain with a maximum of around 20 dB at 330 GHz, Fig. 1(c) blue curve. Finally, Fig. 1(d) shows the normalized vertical component of the electric field from a top view at 310 GHz. Analyzing it in detail, it is clear that we achieve a planar wavefront in the direction of propagation.

III. Conclusion

To sum up, this article presents the design of a hyperbolic lens excited by a GGW horn antenna at 300 GHz. The GGW horn antenna has been designed and combined with the metasurface in order to achieve excellent radiation characteristics. The results achieved for the system opens new opportunities for the design of directive antennas at high frequency using a planar design.

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