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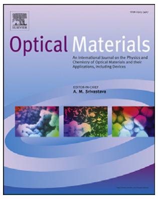

Short Communication

A near zero refractive index metalens to focus electromagnetic waves with phase compensation metasurface

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ABSTRACT

Metamaterials have been widely used to enhance radiation characteristics of antennas thanks to their ability to manipulate the electromagnetic waves. Recent progress has shown that flat metasurfaces with reduced tunable dimensions are capable to provide a near zero refractive index and a phase compensation mechanism which are responsible for the focusing of electromagnetic waves. Here, we present a study, about two types of flat metasurface lenses operating at the frequency of 5.9 GHz for the improvement of a patch antenna radiation properties and bandwidth at the same time. The proposed structures can be used in wireless point to point communication and especially for WAVE applications.

1. Introduction

The range of metamaterials(MTMs) applications is very broad starting from imaging applications to the improvement of antenna radiation properties. Patch antennas that are potential candidates in wireless communication thanks to their low profile and ease of integration, are suffering from narrow bandwidth and low gain. Metamaterials were used as a superstrate lens in order to mitigate such limitations and to improve the radiation properties of patch antennas. In addition, metamaterials have shown great potentials in manipulating the electromagnetic waves on a subwavelength scales thanks to their unique electromagnetic properties that are not available in natural materials such as negative refraction index, super imaging and invisibility cloaking [1,2]. The key aim of using metamaterials to focus electromagnetic waves was to avoid some drawbacks presented by conventional lenses such as curved shape and bulky size. Starting from perfect lens [3], super lens [4] to hyper lens [5], all those metamaterial lenses can overcome the diffraction limit by controlling the evanescent waves.

Thanks to this potential ability of manipulating the electromagnetic wave, MTM based device have been designed and experimentally validated either for microwave applications or at optical frequencies. For example, optical MTM structures have been used to guide the optical wave exploiting the balance between the dispersion and the non linearity presented in MTM. In addition, by designing the structure geometry and by selecting the appropriate metal, we can easily tune the dispersion profile and guide the optical wave in bended waveguide [6,7].

When it comes to microwave domain, MTM with Gradient Refractive Index (GRIN) or with Near Zero Refractive Index (NZRI) have been widely used to enhance the directivity and achieve a high gain for antennas [8,9]. The most important application of Epsilon Near Zero(ENZ)MTM is the possibility of squeezing the guided electromagnetic wave by allowing a zero phase delay thanks to the anomalous properties present in such MTM [10]. This squeezing phenomenon occurred regardless the shape or the geometry of the waveguide which provide the ability for bending the channel. Ultrathin planar metamaterials called Metasurface, are commonly used to improve the radiation performances of antennas and avoid high losses and high fabrication cost of plasmonic metamaterials. The main mechanical advantages of those structures over bulky MTM structures are ease of fabrication and a smaller required volume [11]. The most known type of metasurface are the

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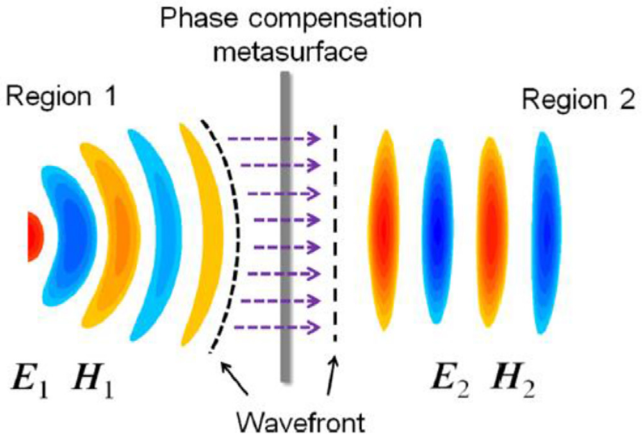


Fig. 1. Phase compensation using tunable metasurface.

Partially Reflecting Surface (PRS) and the Artificial Magnetic Conductor (AMC)which are patterned on a dielectric substrate to construct a resonnant Fabry-Perrot cavity aiming to enhance the radiation properties of a patch antenna [12]. The novelty in this work, and different from previous studies on focusing the EM waves based on the use of GRIN and NZRI MTM or Fabry-Perrot Cavity, we propose a metasurface lens with size modified unit cell responsible for creating a gradient phase to compensate the out phase emission from a patch antenna and transform the spherical like wave to a planar one and ensure a directive emission. The gain enhancement is also accompanied with the improve of the bandwidth which is not available in other studies where either the gain or the bandwidth were separately enhanced.

2. Design and simulation of the proposed metalenses

Fig. 1 below illustrate the phase compensation mechanism which consist on the transformation of the spherical like phase of a patch antenna into an in-phase profile allowing a directive emission of the propagative wave.

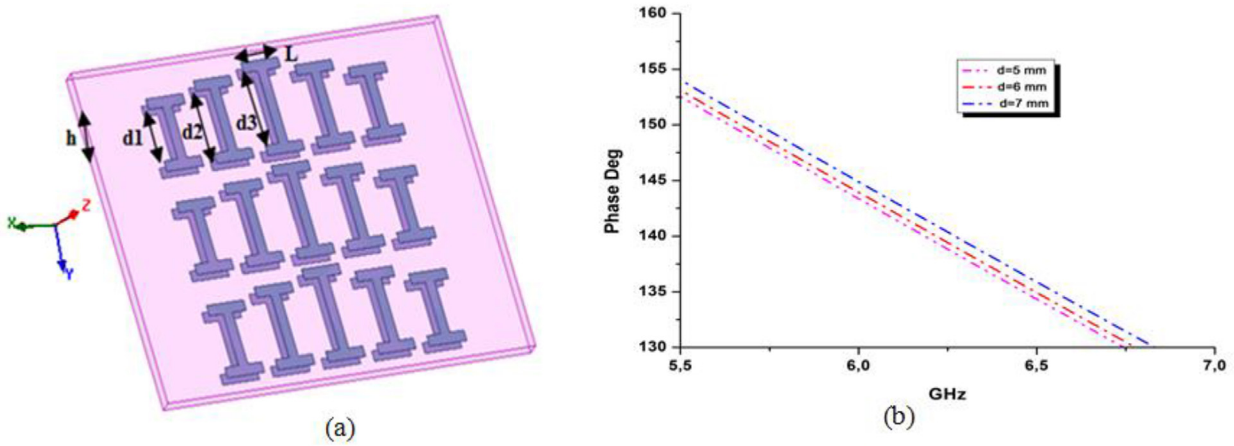
From a theoretical point of view and based on the study of reference [13], it was revealed that a well designed metasurface structure, is characterized by surface electric and magnetic impedances. Those impedances can be tuned by changing the geometric shape of the unit cell to control the transmission magnitude and phase of the propagative electromagnetic wave. Henceforth, by designing the metasurface lens with a size modified unit cell, a phase shift will occur along the structure allowing a phase compensation mechanism and producing an in-phase rather than out of phase emission. In addition, assuming that our metasurface lens obey to Huygens principle, we can say that both the scattering amplitude and the phase shift are intrinsically wavelength dependent at the operating frequency. So, in the aim to have an improved operational bandwidth the phase shift of the metasurface unit cell should be linear frequency dependent as it is in our case where the linear relation between phase shift and frequency is illustrated in Fig. 2-b. Here in this work we do a comparison study between two $40 * 32$ mm^2 metasurface based lenses. The first one is a single layered metalens(SLML) comprised of periodically distributed 5*3 I shaped unit cells printed on the top layer of the substrate. For the second metalens which is the double layered metalens(DLML) or the bilayered metalens, an identical symmetrical slots were printed on the bottom of the dielectric substrate. All the slot units were made from copper. The layout of the proposed structures is depicted in Fig. 2-a.

By varying the geometric parameters of each I shaped slot unit, an abrupt phase change is obtained at different positions that enable the phase compensation mechanism leading to the focus of electromagnetic wave. To do this we have used three sizes of the unit cell $d_1 = 5$ mm, $d_2 = 6$ mm and $d_3 = 7$ mm with a subwavelength gap of 1 mm between the slots as depicted in Fig. 2 above.

When an oscillating electric field is applied to the metasurface lens, a considerable interaction occurs between incident wave and surface plasmons of unit cells which is responsible of the phase shift. So, we can assume that the unit cells with spatially varying geometry behave like resonators, giving rise to phase discontinuity and permit the focusing mechanism accordingly [14,15].

The electromagnetic properties of the proposed metalenses were numerically demonstrated by simulation using the software HFSS where the incident wave was linearly polarized along the z axis.

Fig. 3 above shows the scattering parameters for a double layered and a single layered metalens. For both metalenses, the



(a)

(b)

Fig. 2. (a) The metalens design with d1 = 5 mm, d2 = 6 mm,d3 = 7 mm,L = 4 mm and h = 136 mm, (b) Phase shift for the three different sizes of unit cell.