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APPLICATIONS OF METAMATERIAL NEGATIVE REFRACTIVE INDEX LENS (MNRI-LENS)

Mohit Anand
Department of Electrical Communication,
Indian Institute of Science,
Bangalore-560012, India

***Abstract*—Lenses are the most commonly used basic elements in optics and microwave applications. Imaging and focusing are fundamental functions of any lens. Metamaterial negative refractive index lens has power to focus the source field with flat geometry. In this paper various possible applications of metamaterial negative refractive index (M-NRI) lens are investigated.**

***Index Terms*— Left handed materials (LHM), Metamaterials (MTM), Negative refractive index (NRI), dispersion, Metamaterials negative refractive index (M-NRI), Multiple beam antenna (MBA), Intelligent Transport System (ITS), Extraordinary transmission medium (ETM).**

I. INTRODUCTION

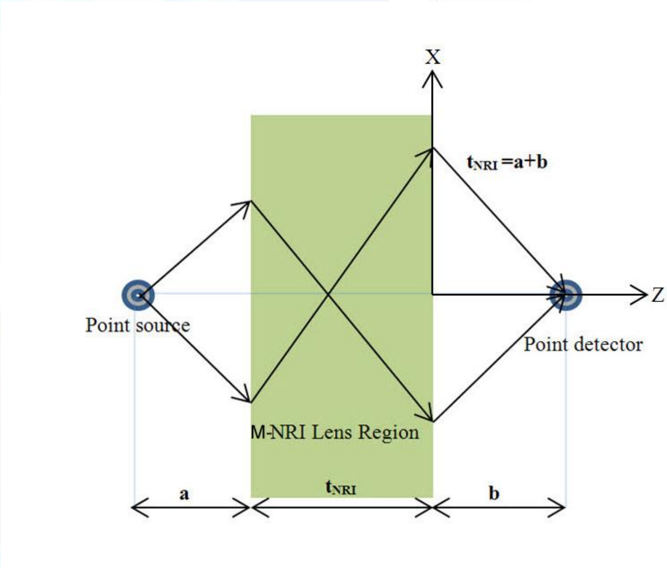
The negative refraction of the perfect lens has attracted many researchers and experts of Optics, RF and Antennas. The concept of negative refraction was first discussed in 1904 by Schuster in his book, An Introduction to The theory of Optics in 1904 [1]. The novel properties of such metamaterial lens could lead to a “perfect lens” that allows direct observation of an individual protein in a light microscope or, conversely, invisibility cloaks that completely hide objects from sight. They also have shown the possibility of designing, ‘Superlenses’ and ‘Hyperlenses’ for sub-wavelength imaging in realistic lenses with new types of appropriately tailored artificial materials. In this paper we have discussed the possible applications of these M-NRI lenses in Optics, RF and health care sectors.

Metamaterial Negative Refractive Index (M-NRI):

Refractive index (n) of any homogeneous isotropic material is defined in terms of its relative permittivity (ε_r) and permeability μ_r as:

$$n = \pm\sqrt{\varepsilon_r \mu_r} \tag{1}$$

$$\varepsilon_r = 1 - \frac{\omega_{pe}^2}{\omega^2 + j2\omega\delta} \tag{2}$$



$$\mu_r = 1 - \frac{\omega_{pm}^2}{\omega^2 + j2\omega\delta} \tag{3}$$

Fig. 1. Focusing by flat metamaterial negative refractive index (M-NRI) lens

desired permittivity and permeability of the artificial medium can be tailored by setting ω_{pe} (electric plasma frequency), ω_{pm} (magnetic plasma frequency) and loss factor δ in Equation 2 & Equation 3.

If permittivity and permittivity simultaneously becomes negative, then to satisfy the causality condition, the square root of the products of these permittivity and permeability resulting in negative index of refraction Equation 4.

$$n = -\sqrt{\varepsilon_r \mu_r}\ ,\ if\ \ \varepsilon_r\,,\mu_r < 0 \tag{4}$$

There are several consequences of this M-NRI medium [3]:

a. Reversal of Snell's law
b. Focusing by flat lens
a. Negative refraction at the interface between a Right handed medium and Left handed medium.
b. Interchange of convergence and divergence effects in convex and concave lenses, respectively, when the lens is made M-NRI medium.

Limitations:

However this M-NRI medium is inherently lossy in nature and losses are the major obstacles that limit their practical deployment. Various fabrication challenges are also involved in realization of M-NRI medium. Not much experimental validation results are available. Several schemes have been made to compensate for the losses in M-NRI medium. In this paper we have investigated the possible applications of these new kinds of structures.

II. **M**-NRI LENS FOR ANTENNAS

Many experiments have been conducted for applying metamaterials negative refractive lens to antennas and microwave devices. In this study, the application of high directive antennas, multiple beam antennas, parabolic lens antennas, single beam adaptive beam forming antennas, beam scanning antennas and Luneburg antennas to metamaterial negative refractive index (M-NRI) lens is investigated.

A. High Directive Antennas:

Graded index M-NRI lens provides multifunctional and efficient alternative for high directive antenna applications. M-NRI property can be used to introduce into these lens antennas for controlling refractive index, wave impedance and polarization of lens antenna. Theoretical modeling and prototype demonstration of such high directive M-NRI lens are proposed by [4] .The proposed M-NRI lens can transform spherical wave front into the planar wave front to enhance the directivity of antenna system. These high directivity antennas can be used for applications such as radar and satellite communication system.

B. Feed for Multiple Beam Antennas:

Over the past decade, there has been a rapid growth in the use of multiple-beam antenna (MBA) systems for satellite communication applications such as high-speed Internet applications, personal communication satellites (PCS), direct-broadcast satellites (DBS) and military communication satellites. These antennas generally provide contiguous coverage over a specified area by using high-gain multiple spot beams for uplink and downlink coverage. The MBA system needs multiple reflectors, each of which supports both transmission and reception of signals. Such systems also require a plurality of feed horns for illuminating each of the reflectors. For each individual reflector, feed directivity and efficiency limits the effectiveness of the antenna system. In particular, an inadequately directive feed horn causes an energy spill over the reflector that can account for up to a 3 dB gain loss, and can also affect pattern performance on the ground. Any multiple beam antenna system requires at least one reflector antenna and multiple numbers of feed horns for feeding that reflector. A metamaterial lens is interposed between the plurality of feed horns and the at least one reflector. The metamaterial lens may provide an overlapping element distribution from at least two feed horns of the plurality of feed horns. In one of the feed horn, metamaterial lens has an index of refraction between zero and close to one. In another feed horn the metamaterial lens is comprised of one or more Zero Index materials (ZIM), Low index materials (LIM) and Graded index materials (GRIN) that may have refractive index below one or above one .The metamaterial lens is spread over a large area than a horn aperture which originates a substantially uniform phase distribution. This spreading of energy by metamaterial lens can help to achieve overlapping beams from adjacent feed horns where the overlapping beams demonstrate a large effective aperture than feed horn. Since the amplitude and phase of aperture distribution varies over a width of horn apertures, this aperture distribution can be made uniform by appropriately tailoring the property of metamaterial lens. [5]

C. Parabolic Lens Directive Antennas:

Extraordinary transmission medium (ETM) parabolic lens can be used for antenna directivity enhancement [6]. ETM parabolic lens made of M-NRI materials can focus plane wave at the input of this lens at the image plane. ETM-parabolic lens can be constructed by stacking different layers of M-NRI flat slabs of varying thickness depending upon desired refractive index profile of parabolic lens.

D. Single Feed Adaptive Beam forming Antennas:

The M-NRI implementations of beam scanning antennas have been proposed by [7]. The beam scanning Transform Electromagnetics (TE) lens allows arbitrary number of beams at controlled magnitude to be dynamically synthesized from a single omnidirectional source. Beam scan can be performed without complex phasing and amplitude adjustment networks for array system with equivalent performance. By changing the effective shape of the lens, radiation pattern can be altered. This lens offers potential for fast solid-state-multibeam control with application to advance terrestrial communication systems and adaptive radars.

E. Beam scanning lens Antennas:

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In recent years, there is rapid increase in motorization; urbanization and population are increasing worldwide. Traffic congestion problem is also increasing day by day. Intelligent Transport System (ITS) that uses information technology for simulation and real time communication networks is used to manage and solve this problem. Among such ITS applications, high performance antennas are essential tools to transmit/receive electromagnetic signals to detect the vehicle and obstacles around and measuring the distance and speed. High performance antennas with beam scanning capabilities are required for this purpose. Lens antennas are good candidates for this purpose. These lenses are usually made of curved surfaces that make their production and integration very difficult. Easy way to realize the high performance beam scanning antenna using flat M-NRI slab which can be easily mounted on the vehicle instruments for different ITS applications. These planar lenses can transform the cylindrical waves emitted from the source (line source) into planar waves or can focus the incoming plane wave to a point and hence planar lens can be designed as a high gain antenna .When the source moves along the focal plane, the radiated beam of antenna will scan within a designed angle generating the beam scanning lens antenna. [8]

F. Substrate Integrated Luneburg Lens Antenna

Lenses have been important optical devices for imaging applications. However, in these lenses, there always exist aberration problems. The use of the other type of lenses such as Luneburg lens, have a gradient of decreasing refractive index radically out from its center which can eliminate the aberration. Main difficulty with Luneburg lens is the manufacturing of the gradient-index materials and their spherical focal surfaces, which are hardly matched to the planar array of sources or detectors. Recently, a new imaging lens was proposed using the transformation optics and was realized in the microwave frequency [9]. Such a lens overcomes the aberration problem

Substrate integrated Luneburg lens is very compact. Compact and small electrical size aperture directive broadband Lens antenna is proposed by [10]. The surface integrated Luneburg lens proposed is based upon embedding small broadband planar antenna (such as Vivaldi) inside a parallel plate waveguide to illuminate the Luneburg lens. In this lens, focusing condition is achieved by graded index M-NRI materials.

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III. **M**-NRI LENS FOR SUPERLENS

The light emitted from a source includes not only propagating waves but also evanescent waves. This emitted wave carries the sub-wavelength detail of the source. The evanescent waves decay exponentially in positive refractive index medium and cannot be collected at the image plane by a conventional lens, which result in a diffraction-limited image which is not the complete image of the source object. But if the lens medium is made of M-NRI then the near-field Evanescent waves can be strongly enhanced across the lens. After emerging from the M-NRI lens the evanescent waves again starts decaying until their amplitudes reach their original level at the image plane. However the propagating waves from the source passes through the M-NRI lens with negative refraction and a reversed phase front which leads to zero phase change at the image plane. By completely recovering both propagating and evanescent waves in phase and amplitude, a perfect image can be created and this modified type of lens is Superlens. [11]

IV. **M**-NRI LENS FOR WIRELESS POWER TRANSFER

In recent years, peoples have experienced a big revolution in terms of the number of autonomous electronic devices in their everyday lives e.g. mobile phones , laptops, palm pilots, digital cameras, household robots etc. These devices are usually powered by batteries, which need to be recharged frequently. This fact motivated many researchers to work on the feasibility of wireless power transfer applications. It has been shown theoretically and experimentally by [ ] that the near-field electromagnetic coupling between two resonant coils can be enhanced by a slab of M-NRI lens which assists to improve the power transfer between the resonant coils wirelessly. [12]

V. **M**-NRI LENS FOR BIOMEDICAL APPLICATIONS

In biomedical applications, microwaves are used to destroy diseased soft-tissue by heating the tissue to a temperature that causes cell death. This process is known as ‘hyperthermia’ in medical terminology The source produces microwave energy which is transmitted through the antennas into the patient diseased tissue thereby elevating the temperature that causes the tumor cell membrane damage, which leads to the destruction of the cancer cells. In Hyperthermia treatment of cancer, It requires controlled and carefully directed dose of heat to the cancerous tumor and surrounding body tissue. Since the most important property of M-NRI lens is their ability to focus the electromagnetic field of a source .Hence it can be used for appropriate focusing spot in biological tissue. Flat M-NRI slab can be used as a lens to focus microwave in Hyperthermia treatment of cancer [13].

VI. **M**-NRI LENS FOR METASPACERS

Practical spacers ideally, require sufficiently low-loss, and non-dispersive operation near operating frequency band. Theoretical investigation of possibility of using a M-NRI structure, as a spacer, named as meta-spacer has been performed by []. The proposed meta-spacer can provide new optical properties that are not possible through conventional spacers. Negative index meta-spacers embedded in fishnet metamaterial structures has been investigated and compared them with conventional fishnet metamaterial structures. The results show that the negative index meta-spacer based fishnet structure exhibits intriguing inverted optical response. [14]

VII. CONCLUSION

In conclusion, we can say that metamaterials negative refractive index (M-NRI) lens is one of the active fields of research in the past few years. Metamaterial lens with light weight, compact and free space matched impedance have a very bright future in practical realizations in communication, optics, radar and imaging applications. If current technical limitations can be overcome, then M-NRI lens could become an ideal technology for various other applications. This M-NRI lens has the potential to enable a multitude of new devices that can bring them into the marketplace and may become an intricate part of everyday technologies.

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