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# A Review Paper on Metamaterial

**Priyanka**
[*] Electronics and communication engg. Iet Bhaddal Ropar , india

## Abstract

In this paper a brief review about metamaterials is given. Here we discus different type of metamaterials composite structure used in antenna engineering. Compared with the conventional materials, metamaterials exhibits some specific features which are not found in conventional material. after that metamertaials based antenna, also describe the parameter of antenna like gain and bandwidth which can improve by using metamaterials and discuss future scope and application of metamaterials.

**Keywords** Patch Antenna, Metamaterial, Left handed materials (LHM), Negative refractive index (NRI), dispersion,strut

## Introduction

The Microstrip based configurations is its low profile, light weight nature, conformability to planar and non-planar structures and ease of fabrication. But this type of antenna having some disadvantages also such as its narrow band width and low gain. [1][2]
To overcome these drawbacks we used an artificial homogeneous material called Metamaterial. Metamaterials is an artificial material which has negative value of $\varepsilon$ and $\mu$ but the entire natural material find in the nature has positive value of $\varepsilon$ and $\mu$. To date they have been realized mainly as composite artificial media formed by periodic arrays of dielectric or metallic inclusions in a host substrate. The "meta" refers to the resulting effective properties whose electromagnetic responses are "be-yond" those of their constituent materials. Metamaterials, particularly left handed metamaterials (LH MTM) characterized by a simultaneously negative permittivity and permeability as well by a negative refractive index, have been proposed for the realization of many different types of microwave components having advanced characteristics and small size. Winston E. Kock developed materials that had similar characteristics to metamaterials in the late 1940s. Materials, which exhibited reversed physical characteristics, were first described theoretically by Victor Veselago in 1967.According to V.G. Veselago Metamaterial [3] are artificial homogeneous materials which are not available in nature but using the properties of such a material, antenna parameters are easily improve. A little over 30 years later, in the year 2000, Smith et al.[4] reported the experimental demonstration of functioning electromagnetic metamaterials by horizontally stacking, periodically, split-ring resonators and thin wire structures.

## Classifaction of metamaterial

The response of a system to the presence of Electromagnetic field is determined by the properties of the materials involved. These properties are described by defining the macroscopic parameters permittivity $\varepsilon$ and permeability $\mu$ of these materials. By using permittivity $\varepsilon$ and permeability $\mu$ the classification of metamaterials as follows, the medium classification can be graphically illustrated as shown in fig. 1.1.[6]-[8]

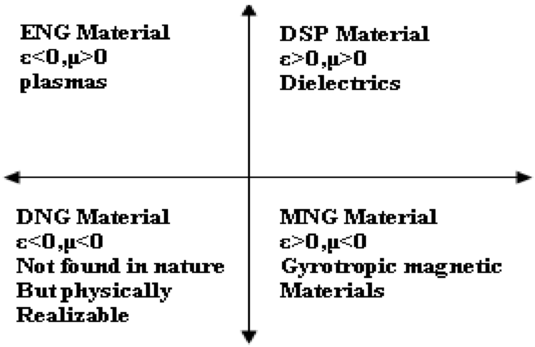

*Fig. 1.1: Metamaterial Classification*

1. DPS (Double Postive Medium)
A medium with both permittivity & permeability greater than zero (e > 0, μ > 0) are called as double positive (DPS) medium. Most occurring media (e.g. dielectrics) fall under this designation.
2.ENG (Epsilon Negative Medium)
A medium with permittivity less than zero & permeability greater than zero (e < 0, μ > 0) are called as Epsilon negative (ENG) medium. In certain frequency many plasmas exhibit this characteristics.
3.DNG (Double Negative Medium)
A medium with both permittivity & permeability less than zero (e < 0, μ < 0) are called as Double negative (DNG) medium. This class of materials has only been demonstrated with artificial constructs
4.MNG (Mu Negative Medium)
A medium with both permittivity greater than zero & permeability less than zero (e > 0, μ < 0) are called as Mu negative (MNG) medium. In certain frequency regimes some gyrotropic material exhibits this characteristic.

## Different types of metamaterial

1. Electromagnetic Metamaterial
A new sub discipline within physics and electromagnetism is introduced by Metamaterials. Such structures are used for optical and microwave applications. This type of metamaterial is divided into further classes, as follows.

***Negative index metamaterials***
The negative index metamaterial (NIM) is also called double negative metamaterial (DNG) because both the permittivity ε and permeability μ are negative resulting in a negative index of refraction. If both μ and ε are negative a backward wave is produced so the other term for negative index metamaterial is backward wave media.

***Single negative metamaterials***
In single negative metamaterials (SNM) either relative permittivity or relative permeability is negative but not the both. The epsilon and Mu negative media is come under the category of SNM. In epsilon negative media (ENG) there is negative relative permittivity and positive relative permeability however opposite in the case of Mu negative media (MNG) . A slab of ENG material and slab of MNG material have been joined to conduct wave reflection experiments. This resulted in the exhibition of properties such as resonances, anomalous tunneling, transparency, and zero reflection.

***Electromagnetic bandgap metamaterials***
Electromagnetic bandgap metamaterials (EBG) controls the light with the help of photonic crystals or left handed metamaterials.EBG have goal of creating high quality, low loss dielectric structures. Both the classes can allow light to propagate in specific designed directions.

***Double positive metamaterials***
In double positive metamaterials (DPS) both the permittivity and permeability are positive and forward wave propagation

***Bi-isotropic and bi-anisotropic metamaterials***
Bi-isotropic media is exhibit with the help of magnetoelectric coupling. Normally we assume that metamaterial l has independent electric and magnetic responses described by the parameters ε and μ. However in many examples of electromagnetic metamaterials, the electric field causes magnetic polarization, and the magnetic field induces an electrical polarization, i.e., magnetoelectric coupling. They are also called bi-anisotropic.

***Chiral metamaterials***
When a metamaterial is constructed from chiral elements then it is called as chiral metamaterial. In chiral the effective parameter K is non zero. Wave propagation properties in chiral metamaterial demonstrate that negative refraction can be realized in metamaterials with strong chirality and positive ε and μ.

2. Metamaterial type based on frequency band
This type is worked on the desired frequency band

***Frequency selective surface based metamaterials***
FSS metamaterial blocked signals in one waveband and pass those at another waveband. It became an alternative to fixed frequency metamaterials.

***Photonic metamaterials***
This interacts with optical frequencies. The sub-wavelength period distinguishes the photonic metamaterial from photonic band gap structures.

***Tunable metamaterials***
Tunable metamaterials has the capability to arbitrary adjusts the frequency changes in the refractive index.

***Terahertz metamaterials***
This metamaterials interact with terahertz frequencies lies between 0.1 to 10 THz. This corresponds to the wavelengths between 3 mm (EHF band) and 0.03 mm (long-wavelength edge of far-infrared light).

3. Plasmonic metamaterials
Plasmonic metamaterials exploit surface plasmons, which are produced from the interaction of light with metal dielectrics.

4. Acoustic metamaterials
Acoustic metamaterials control, direct and manipulate sound in the form of sonic, infrasonic or

ultrasonic waves in any medium alike gases, liquids and solids. Sonic wave can also exhibit negative refraction.

5. Nonlinear metamaterials

Metamaterials can also form with the help of non linear media, as whose properties change with the power of the incident wave. This type of media is essential for non linear optics.

6. Elastic metamaterials

Elastic metamaterials can also called mechanical metamaterials. These type of metamaterials uses the different parameters to achieve a negative index of refraction in materials that are not electromagnetic. A new design for elastic metamaterials introduced that can behave either as liquids or solids.

## Metamaterial antenna

Metamaterial antennas are a class of antennas which use metamaterials to enhance or increase performance of the system. The metamaterials could enhance the radiated power of an antenna. Materials which can attain negative magnetic permeability could possibly allow for properties such as an electrically small antenna size, high directivity, and tunable operational frequency, including an array system. Furthermore, metamaterial based antennas can demonstrate improved efficiency-bandwidth performance.

Artificial magnetic conductors and electrically small radiating and scattering systems are emphasized. Single negative, double negative, and zero-index metamaterial systems are discussed as a means to manipulate their various characteristics.

1. Surface and volumetric AMCs

One significant area of metamaterials research has been the development of artificial magnetic conductors (AMCs) for wireless applications. [9] These AMCs have been realized mainly as high impedance surfaces that produce an in-phase reflection coefficient. All of these surface-based AMCs include a PEC ground plane and thus guarantee, at least, high reflectivity. In contrast, in [10] a volumetric AMC was realized with only the capacitive loaded loop (CLL) based MNG material i.e., there was no ground plane and the CLL element is a simplified form of the SRR. Artificial magnetic conductors have been attained with high impedance and frequency selective surface constructs as well as with volumetric inclusion-based media.

2. MTM based electrically small antenna

The use of metamaterial coatings to enhance the radiation and matching properties of electrically small electric and magnetic dipole antennas has been championed in [11]– [15]. Dedicated matching networks must be designed and added to electrically small antennas to make them efficient radiators Resonances arising in electrically small regions of space where single and double negative materials are paired with common double positive materials to have a great potential for overcoming the limits generally associated with several electromagnetic problems by providing a means to engineer the overall responses of the systems.

3. Zero index MTM based antenna

It has been demonstrated that zero-index metamaterials can be used to achieve high directivity antennas. Because a signal propagating in a zero-index metamaterial will stimulate a spatially static field structure that varies in time, the phase at any point in a zero-index metamaterial will have the same constant value once steady state is reached [16]. Zero-index metamaterials have also been used to achieve a zeroth-order resonance (ZOR) antenna [17], [18].

Zero-index metamaterials, media with permittivity permeability with zero or near zero values, may have strong impact in some applications despite their nonresonant character, since they combine anomalous wave interactions with relatively larger bandwidth and lower losses.

4. Sub wavelength and directive antenna.

Patch antennas have become a favorite choice for many applications, including wireless communications and radars. It would be desirable to miniaturize these antennas while enhancing their directivities and bandwidths, to achieve these goal metamaterial inspired approaches have led to improved aspects of all of these characteristics. The uses of properly designed slow-wave artificial reactive surfaces and magneto-dielectric layers have also been proposed in [19] and [20] to achieve antenna miniaturization. Magnetic metamaterials have been considered for the miniaturization and increase in bandwidth of patch and PIFA antennas in [21], [22]. High-directivity printed dipole and patch antennas have been obtained with combinations of metamaterial based cavity-size reductions and AMC concepts as well as MNG and DNG substrates and superstrates [23]–[25].

## Application area of metamaterial

1. Applications of metamaterials in antenna engineering.

Some unique applications of metamaterial composite structures as an antenna substrate, superstrate, feed networks, phased array antennas, ground planes, antenna radomes and struts invisibility have been discussed.

***Antenna substrate***

Metamaterials are promising candidates as antenna substrates for miniaturization, sensing, bandwidth enhancement and for controlling the direction of radiation [26]. Metamaterial substrate can be used for a variety of applications. It can be designed to act as a high impedance substrate that can be used to integrated low-profile antennas in various components and packages. The high impedance of designed metamaterial substrate prevents unwanted radiation from traveling across the substrate which results in a low profile antenna with high efficiency.

Metamaterial substrates can be designed to act as a very high dielectric constant substrate at given frequency and hence can be used to miniaturize the antenna size. [27]

***Antenna superstrate***

High directive antenna elements can be realized by introducing a set of metamaterial superstrates that can improve the radiating efficiency.[28]-[29]. Metamaterials can act as resonant structures which allow the transmission and reflection of electromagnetic waves in a specific way in certain frequency bands. A dielectric superstrate properly placed above a planar antenna has remarkable effects on its gain and radiation characteristics.

***Array feed network***

Metamaterial phase-shifting lines can be used to develop antenna feed network which can provide broadband, compact and non-radiating, feed-networks for antenna arrays. Metamaterial based transmission line feed networks can be used to replace conventional transmission lines-based feed-networks, which can be bulky and narrowband. These feed-networks have the advantage of being compact in size, therefore eliminating the need for conventional TL meander lines [30].

***Antenna radome***

Radome is a covering to protect an antenna from rain, wind perturbations, aerodynamic drag, and other disturbances. Radome should be made from a perfectly RF transparent and non-refractive material in order to not disrupt radiated fields from and to the enclosed antenna. Metamaterial can be suitably designed to use as Radome. By embedding metamaterial structures inside a host dielectric medium, the desired material parameters of the composite material can be adjusted to desired values of interest. Metamaterial radomes should enhance out of band signal rejection, useful for multiband radomes also.

***Phased array antenna***

A phased array antenna is consists of an array of antennas that enables long-distance signal propagation by directional radiation. Metamaterials can be used to improve the impedance matching of planar phased array antennas over a broad range of scan angles [31]. In recent years metamaterial phase shifters are adopted to fine tune the phase difference between adjacent elements.

***Struts in reflector antennas***

Struts in reflector antenna systems are generally mechanical structures, supporting the feed in a single reflector system or the sub-reflector in a double reflector system.

Conventionally the adverse effect of strut is usually minimized by shaping the struts, but with the advent of meta-materials a new method has also been introduced to minimize these effects. This new approach is based on guiding and launching the electromagnetic radiation in preferred directions and reducing the effect to nearly zero in the operational directions. [32]

***Antenna ground plane***

Metamaterial ground planes also known as artificial magnetic conducting ground planes are widely used as the planar antenna ground planes in order to enhance the input impedance bandwidth. [33] Metamaterials ground planes find important applications in low profile cavity backing and isolation improvement in cavity backed antennas and microwave components respectively. When employed in the ground planes it improves isolation between radio frequency or microwave channels of (multiple-input multiple-output) (MIMO) antenna arrays systems.

2. Absorber

A metamaterial absorber manipulates the loss components of the complex effective parameters, permittivity and magnetic permeability of metamaterials, to create a high electromagnetic absorber. This is a useful feature for solar photovoltaic applications.

3. Superlens

A superlens uses metamaterials to achieve beyond the diffraction limit. The diffraction limit is inherent in conventional optical devices or lenses.

4. Cloaking Devices

Metamaterials are a basis for attempting to build a practical cloaking device. The cloak deflects microwave beams so they flow around a “hidden” object inside with little distortion, making it appear almost as if nothing were there at all. Such a device typically involves surrounding the object to be cloaked with a shell which affects the passage of light near it.

5. Light and Acoustic filtering

Metamaterials textured with nanosacle wrinkles could control sound or light signlas such as changing a material’s color for improving ultrasound resolution. Acoustic metamaterials are artificially fabricated materials designed to control, direct, and manipulate sound in the form of sonic, infrasonic, or ultrasonic waves, as these might occur in gases, liquids, and solids.

6. Seismic protection

Seismic metamaterials are metamaterials which are designed to counteract the adverse effects of seismic waves on manmade structures, which exist on or near the surface of the earth.

## Future scope of metamaterial

Electromagnetic response functions that can offer exciting possibilities of future design of devices & components are reviewed. Some silent properties of metamaterial have been reviewed. The metamaterials research area has evolved into prominence only very recently. Nonetheless, it is already having a large impact on the international electromagnetics community. Metamaterials have revitalized our interests in complex media; their exotic properties; their analysis and numerical modeling; and their potential applications. There have been large strides in our understanding of their anomalous behaviors and of their possible utilization in many electromagnetic applications from the microwave to the optical regime.

The dream of “invisibility cloaks” will be become possible, and although the process will likely take another decade, steps already have been made in that direction. Research on developing a special kind of material that cause Light to bend in unusual ways, following the contours of the material structure and Come back out the same way it went in.

## Conculsion

In this Paper, a short review of history of metamaterials and some of silent features and ideas for metamaterial, various types of metamaterials, various applications of metamaterials has been discussed. The research work presented in this paper summarizes the recent developments and applications of metamaterials in antenna engineering. This review has only briefly touched upon some selective research efforts associated with metamaterials and their antenna applications. Metamaterials, because of their promise to provide engineerable permittivities and permeabilities, possess interesting properties for the design of next-generation structures for radiating and scattering applications.

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## Author Biblography

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|  | **Athor Priyanka**<br>Priyanka received his B.Tech degree from PTU Jalandhar in 2009. She is currently pursuing his M.Tech(part time) from Regional Centre PTU, IET Bhaddal. She has more than 3 years of teaching experience. |