Journal of Advanced Research in Nanoscience and Nanotechnology
Volume 2, Issue 2 - 2020, Pg. No. 1-5
Peer Reviewed Journal

Article

A Review of Meta-materials: Classification, Types and its Applications

Pandurang S Valate[1], Mahesh S Mathpati[2]

[1]M.E Student, [2]Assistant Professor, Department of Electronics & Telecommunication Engineering, SVERI'S College of Engineering Pandharpur, Maharashtra, India.

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Corresponding Author:
Mahesh S Mathpati, Department of Electronics & Telecommunication Engineering, SVERI'S College of Engineering Pandharpur, Maharashtra, India.
E-mail Id:
msmathpati@coe.sveri.ac.in

How to cite this article:
Valate PS, Mathpati MS. A Review of Meta-materials: Classification, Types and its Applications. *J Adv Res Nanosci Nanotech* 2020; 2(2): 1-5.

Date of Submission: 2020-09-03
Date of Acceptance: 2020-11-03

ABSTRACT

Meta-materials are one of the most significant and interesting topics for the Electromagnetic field since past few years. It is artificially invented materials that shows the unique and magnificent properties which are not detected in easily occurring materials. These materials have negative permittivity and permeability. Use of meta-materials in different antenna constructing and fabrication greatly enhances the antenna parameters such as gain, directivity, radiated power, productivity and bandwidth etc. In this paper we present a review of classification, various types of meta-materials, their applications and advantages.

Keywords: Left Handed Media (LHM), Split Ring Resonator (SRR), Single Negative Material (SNG), Double Negative Material (DNG) and Electromagnetic Band Gap (EBG)

Introduction

The word "Meta" is taken from Greek whose meaning is "beyond" or 'superior'. In recent years, behavior of electromagnetic meta-materials great considered for the numerous practical engineering requests like communication field. Meta-materials were first known as left-handed media. The concept of LHM was proposed by Veselago in 1968. The term of meta-materials come from in the reality of year 2001 by R.M walser. He has suggested the classification of meta-materials as a macroscopic mixture giving a man-made, 3d, periodic cellular architecture intended to generate an enhanced combination, not accessible in nature, of two or more reactions to a specific innervation.[1] The John Pendry identified a practical way to make Left-Handed Meta-materials (LHM) which did not follow the conventional right hand rule.[5] A meta-material is a sort of artificial synthetic composite material with a specific structure, which exposes properties non discoverable in natural materials. In the narrow sense, a meta-material is mainly intended founded on a periodic structure trying at novel electromagnetic assets, e.g. negative permittivity or permeability, zero refractive index.[6] Meta-material structure includes of Split Ring Resonators (SRRs) to create negative permeability and thin wire elements to generate negative permittivity. SRR is a novel design consisting of two concentric rings with a split on each ring. Split ring resonators can result in an effective negative permeability over a particular frequency region. Mostly four kinds of meta-material structures are there as antenna substrate: 1-D Split Ring structure, Symmetrical Ring structure, Omega structure & S structure.[7] The first Meta-material which can bend electromagnetic radiation is created by Dr. Smith and his team at the University of California. The meta-materials are refracted in a contrary way as compared to the normal refractive materials.[8] Generally uncommon property that meta-material have is maybe negative refraction which is attained when both the permeability and permittivity of a medium are negative.[9] For obtaining negative permittivity and negative permeability, array of metallic wires and split ring resonators can be used respectively which was a composition of split ring resonator and thin wire.[10] A circularly periodic EBG substrate has been designed to enhance the performance of printed dipole antennas and micro strip slot antennas.[11] A meta-material is usually implemented in a periodic arrangement of unit cells. A unit cell is a combination of Split-Ring Resonator (SRR) and wire structure.[13] Nowadays, the use of meta-material in technology is rapidly growing. Meta-material structure which can either be Artificial Magnetic Conductor (AMC), Frequency Selective Surface (FSS) or Electromagnetic Band Gap, provides more advantages in communication electronic technologies such as antenna.

Classification of Meta-Materials

The meta-materials are classified four groups or quadrants depending on permittivity ε and permeability μ, as shown in following Figure 1.

Zero Index Material: When both permittivity (ε) & permeability (μ) are zero, which fall at the origin of Fig 1, have been called as zero-index materials.[1]

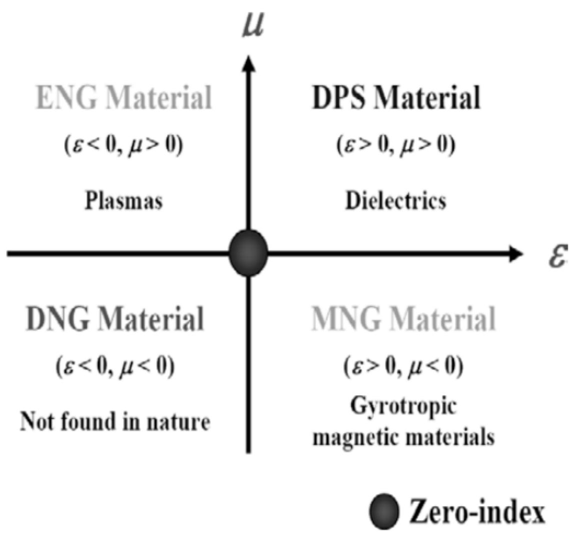

Figure 1.Classification of meta-materials depending on the ε and *μ*

The first quadrant, (ε >0, μ>0) shows right handed material (RHM). The forward Propagation of wave takes place in the first quadrant. The materials which have both permittivity & permeability greater than zero (ε > 0, μ > 0) are called as double positive (DPS) materials. It is generally used material. It follows the right-hand thumb rule for the direction of propagation of wave. For example, most occurring media like dielectrics fall under this designation.[1-5]

The second quadrant, a material has permittivity less than zero and permeability greater than zero (ε < 0, μ > 0) describes electric plasmas which support evanescent waves, or it is called as Epsilon Negative (ENG) material. It is the thin metal wire structure which shown in figure 2. This structure consists of thin parallel conducting wires. When excitation electric field E is parallel to the axis of the wires so as induce a current along them and generate equivalent electric dipole moments. For example noble metals such silver or gold will exhibit this characteristic in the infrared and visible spectrums.[1-3,5,9]

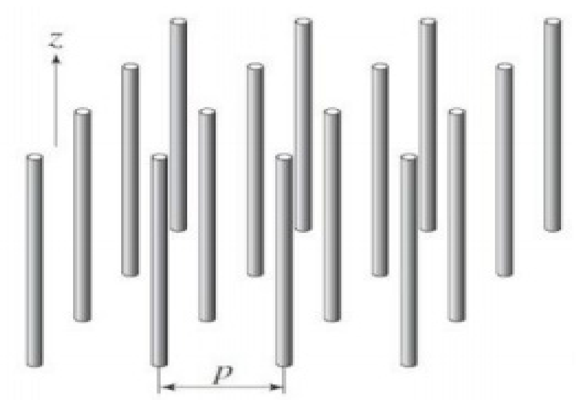

Figure 2.Thin-wire (TW) structure exhibiting negative ε/positive *μ*

The third quadrant, if a material has permittivity & permeability less than zero (ε < 0, μ < 0) it is termed as double negative (DNG) material. This class of materials can only be delivered artificially. It is also called left-handed material. It follows the left-handed rule because propagation of wave takes place in backward direction in this medium. An improved 2D version of LHM shows in figure 3 which allowed the first new confirmation of negative refraction.[1-5,7]

Figure 3.2D Left-handed material

The fourth quadrant, if a material has permittivity larger than zero & permeability fewer than zero (ε > 0, μ < 0) it is described as Mu Negative (MNG) material. In some frequency methods, some gyro tropic material exhibits these characteristics. It is the metal split ring resonator structure (SRR).[1,5]

Types of Meta-materials

Electromagnetic Meta-materials

These meta-materials are basically used in the field of microwave and optics such as microwave couplers, beam steerers, antenna radomes, modulators, lenses and band pass filters.

Single Negative Meta-materials (SNG)

It has either negative ε or negative μ, but not both. The adding of two SNG layers into one creates another form of DNG meta-materials.[4-5]

Double Negative Meta-materials DNG

It is very famous class of meta-materials. DNG are the meta-materials that have both ε and μ is negative with negative refraction index. These are also called as negative index meta-materials (NIM) or these are also known as backward wave media.[4-5]

Electromagnetic Band Gap (EBG) Meta-materials

EBG meta-materials control the propagation of light. This will succeed either by photonic crystals (PC) or left-handed materials (LHM). Both narrative sessions have artificial structure that influence and control the propagation of electromagnetic waves.[4-5]

Photonic Meta-materials

Photonic meta-materials which shown in fig.4 are the type of electromagnetic meta-materials. It is an artificially fabricated, sub wavelength; periodic structure that designed to interact with optical frequencies (ranging from 0.1-10 THz)[2] so called Optical meta-materials. Photonic meta-materials radiate the source at optical wavelengths. These have zero indexes of refraction.[4,8]

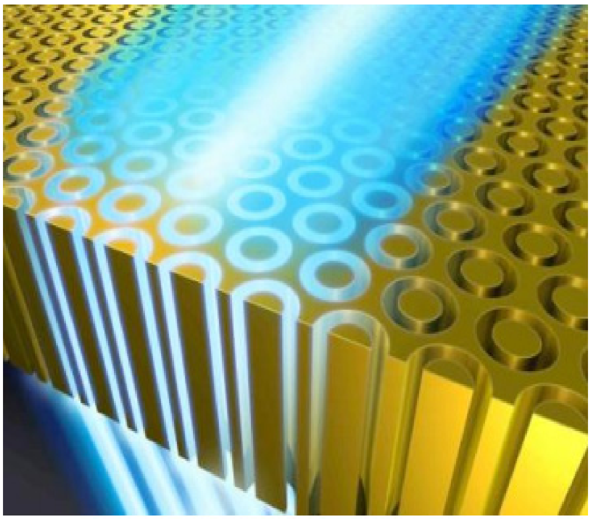

Figure 4.Photonic Meta-materials

Tunable Meta-materials

These are the meta-materials that might accidentally change the frequency of a refractive index.[4] Tuning in the near infrared range is achieved by varying the permittivity of nematic liquid crystal. The meta-materials can be tuned from negative index values, to zero index or positive index values. In addition, negative index values can be improved or declined.[5]

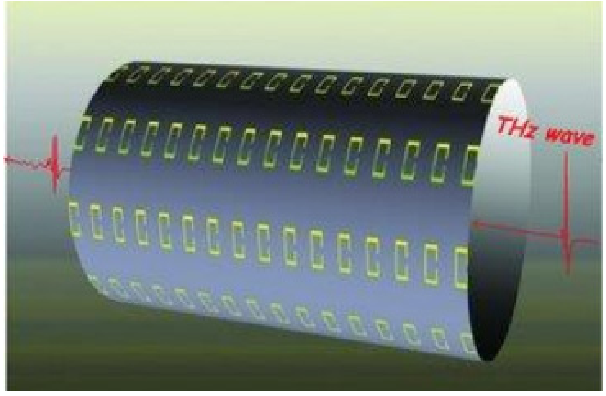

Figure 5.Tunable Meta-materials

Terahertz Meta-materials

Terahertz meta-materials are meta-materials which interact at terahertz frequencies. For research or applications of the terahertz range for meta-materials and other materials, the frequency range is usually defined as 0.1 to 10 THz.[4] These meta-materials with negative values of permeability can accomplish a required magnetic response is termed passive materials. As of this, “tuning” is achieved by fabricating a new material with slightly altered dimensions to create a new response.[5]

Applications of Meta-materials

Meta-material as Cloaks

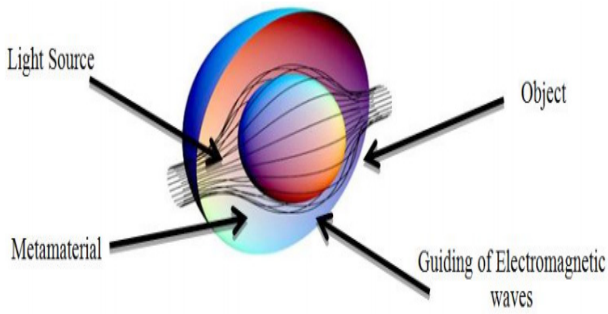

Figure 6.Meta-material as cloaks

The popular display of invisible cloaks has been done empirically in microwave region. This method gives the chances for the control of electromagnetic waves. In 2009 a group of researchers declared cloaking at optical frequencies. In this case the cloaking frequency was concentrated at 1500 nm (in infrared range). The meta-material acoustic cloak is intended to hide objects hidden in water. The acoustic cloak showed efficacy for the sound wavelength of 40 kHz to 80 kHz in 2011.[1] Cloaking can be achieved by cancellation of the electric and magnetic field generated by an object or by guiding the electromagnet wave around the object. Guiding the wave means transforming the coordinate system in such a way that inside the hollow cloak electromagnetic field will be zero this makes the region inside the shell disappear.[3]

Meta-material as Sensor

Meta-material opens a door for designing sensor with specified sensitivity. Meta-materials provide tools to significantly enhance the sensitivity and resolution of sensors. Meta-material sensors are used in agriculture, biomedical etc. Biosensors are especially important tools in many areas, like environmental monitoring, food safety and disease diagnostics in the investigation of biological phenomena's.[5]

Meta-material Antennas

The meta-materials antennas are used to increase the gain of an antenna because it has a unique band gap features and periodic structures. Meta-materials having negative permeability (μ) may permit some estates like high directivity and better optional frequency and radiate power enhancement is possible with the use of Meta-materials in an antenna system.[4-5,8]

WMD Detectors

Air force and Army scientist utilizes metamaterials to identify the existence of chemical explosives, biological agents and contamination. The identical structure and science is utilized for cargo and screening passenger.

Super Lens

A super lens uses metamaterials to achieve resolution beyond the diffraction limit. The diffraction limit is inherent in traditional optical devices or lenses.[5]

Meta-material Absorber

To create a high ratio of electromagnetic radiation absorption, it requires effective medium design, permittivity and magnetic permeability.[5] The first absorber was made by Landy et al. He used three layers, two metallic and one dielectric and proved an absorptivity of $A \approx 99\%$ at 11.48 GHz using metamaterials. A metamaterials absorber manipulates loss components of the complex effective permittivity and permeability, to create a high magnetic absorber. This is a useful feature of solar photovoltaic applications.[13]

Meta-materials Advantages

Bandwidth Increased

By use of superstrate of meta-material over traditional patch antenna or by loading of LHM the attained bandwidth increases.

Directivity Increased

Meta-materials have innate property that regulates the direction of EM radiation to accumulate the making energy in a small angular domain all over the ordinary to the surface. A DNG material enhances the directive assets of an antenna.

Radiated Power improvement

A small dipole antenna surrounded with DNG meta-materials is used to enhance the radiated power much more as equated to traditional patch antenna.

Beam width and side lobes

The meta-materials antennas decrease the beam width and side lobe ratio and thus enhance the directivity and reduce the return loss of antenna.

Conclusion

In this paper, a short review of metamaterials classification, its various sorts and different applications & advantages have been discussed and reviewed. Some of the concluding observations from the review are as- negative refractive index materials or left-handed materials have drawn special attention in microwaves. The employment of metamaterials is helpful for enhancing the antenna parameters like size reduction, gain improvement, directivity, low loss, efficiency and pleased bandwidth requirement that provide exciting possibilities of future design of devices or antennas. The requests of metamaterials for different applications have also been discussed. The extra-ordinary properties of Metamaterials make them an emerging and exciting field of research.

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