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Study of Meta-Materials as an Emerging Technology in Microwave and Millimeterwave Wireless Communication

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Abstract

The meta-materials are synthetically developed materials designed to achieve better electromagnetic radiation which doesn't occur in naturally occurring media. The microwave and millimeter-wave wireless communication systems which employs the components and guiding structures like waveguides, cavity couplers, power dividers, radiating devices like antennas where the frequency of the operation remains high, efficient radiation and electromagnetic behavior of system plays an important role. In such applications, especially millimeter-wave frequency which uses a wireless channel of 60 GHz, the meta-materials have proved to be a boon. The paper presents a literature review of meta-material technology and its applications in the field of wireless communication.

Key Words: Meta-materials, electromagnetic, radiation, wireless

1. Introduction

The naturally occurring materials exhibit the properties which are found in nature. In the world of electromagnetic engineering emanation of radiation i.e. the performance of the device on the lines of its electromagnetic behavior is of the great significance. The dielectrics, substrates, metallic coils, patch or conducting material used in energy storing devices like capacitors, inductors, the radiating structures like antenna and guiding structures like waveguides, advances like MIMO systems in millimeter-wave systems in case of all are affected by the frequency of the operation. The best example is lossy behavior of electromagnetic capacitors employing dielectric material as naturally occurring media at frequencies exceeding over a certain range of GHz. This happens because the dipoles are generated at high frequencies that make the dielectric material lose its inherent properties and results into degradation of the performance of the system. This marks the necessity of some newly developed materials which have some newly defined properties than the original ones resulting into improved electromagnetic behavior when the system .The meta-materials have the properties due to arrangement, position of constituent entities and structural traits, the deployment of which results into better material properties which aids the development of good applications in the field of electromagnetic engineering.

1. A. Microwave Communication Systems

The microwave communication systems are based on the transmission of the data by means of EM waves whose frequency roughly ranges from 1 GHz to 300 GHz and wavelength corresponds from 1cm to 30 cm. The microwave antennas are the direct beam antennas which direct the beam heading directly to the receiving antenna and the point to point radio communication link is generated. The microwaves have the problem of radiation-stemming for which they are supposed to have lower intensity at rectennas. The wireless power transmission using microwaves is possible

1. **B. Milli-Meterwave Wireless Communication**

Millimeter-wave wireless communication is the next step for current wireless evolutions in which the wireless may hold up the wire with the compatibility of its existing speed. The 60 GHz wireless channel is of great significance in millimeter-wave communication systems. The unlicensed spectrum in 60 GHz, oxygen spectrum band which is a part of broader millimeter-wave band is suited for short haul indoor and outdoor applications. The 60 GHz channel is modeling is one the major challenges in design of any real application in millimeter-wave wireless communication. Millimeter-wave frequency band show line of sight radio propagation blocked by obstacles such as buildings and the foliage causes attenuation. The millimeter-wave band is famous for use in radio astronomy and remote sensing for satellites.

2. **Negative Index Materials**

Negative index meta-materials also known as negative index materials (NIM's). In such type of materials, over a certain values of frequency, the refractive index of the electromagnetic wave turns out to be negative. The unit cells forms the main part of NIM's having dimensional smaller than the propagating wavelength for an EM wave.

The unit cells are developed by the use of conducting wires and dielectrics. These cells repeated and stacked in a specific configuration gives rise to an individual NIM material. These materials are responsible for changing the direction of the EM wave and diffract in different way as compared to the conventional or positive index materials. The different types of name given to such materials are Left Handed Media (LHM) or Left Handed Material (LHM), Backward Media or Doubly Negative Materials (DNM). These materials can be used to reduce the size of antennas and other RF components which has a significant effect on the design of radio communication systems. The process of testing and verifying the practicality of these devices is going on. The circuits for compensation of dispersion and filtering using negative index material may find application in near future. NIM's are the materials that are advanced from microwave frequencies to the visible region and prudent designs are taken. The size of Split Ring Resonator (SRR) is pulled down nearly up to 90 nanometers so that the magnetic response can be observed at optical frequencies. The value of permeability in SRR decreases and finally it stops so that it reaches the negative value in the visible region. The one of the most potential applications of meta-materials is achievement of perfect image resolution beyond the diffraction limit. If we control the properties of meta-materials, then it is possible to tune and switch EM waves, such type of materials are called as tunable meta-materials. The individual absorption of the electric and magnetic components of the individual electromagnetic waves can lead to almost 100% absorption which forms one of the most interesting applications of meta-materials.

3. **Chiral Metamaterials**

It is possible to develop chiral structures for meta-materials. The objects whose mirror image is non super imposable to that object is chirality.

There always exists cross coupling between the electric field and magnetic field in the chiral medium. The refractive index, phase velocity and polarization changes for the wave propagating in the chiral media. Pendry proposed a Swiss Roll Structure [1] which resembles helix and the structure shows resonance due to inductance of the coiled helix and capacitance between the inner and outer layers of it. Zhang, 2009 developed terahertz chiral meta-materials [1], it comprises of several micrometer scale virtual gold resonators which become chiral by tilting of the loop resonator. Soukouli's group [1] designed a non-planar chiral structure for materials which is formed by two identical SRR's connected by two metallic pillars and separated by dielectric. J C Bose, 1898 was successful in demonstration of optical activity in microwave region [1].

Most of the new microwave devices like polarizer, antennas and waveguides are based on synthetic chiral meta-materials. Zheludev group, 2003 found optical manifestation of 2D planar system [1], it consisted of mono-layered metallic rosette structure arranged in a square lattice

4. Overview of Application in Field of Wireless Communication

The different applications of meta-materials in the field of wireless communication are listed below [2]:

1. Increasing the gain of antennas
2. Decreasing the electromagnetic coupling in antennas used in MIMO systems
3. Electromagnetic Noise Suppression
4. Non-invasion Detection & Microwave Sensing.

Increasing the gain of antennas:

Meta-materials can be used to minimize the surface waves arising from micro-strip patch antennas. The paper [2] shows that the overall gain of the patch antenna can be increased preserving its low profile feature. Jackson, 1985 showed the non-magnetic superstrates for gain enhancement, when the thickness is approximately half the wavelength.

Decreasing the electromagnetic coupling in antennas used in MIMO system:

In MIMO system used in millimeter-wave wireless communication, the antenna elements are placed approximately close to each other because of which the performance is degraded. The largely correlated output causes degradation of the performance of the antenna system. The SRR can be used as insulator to block EM waves, the reduction in mutual coupling between elements is achieved.

Electromagnetic Noise Suppression:

In multilayer printed circuit boards and packages that contains CMOS based devices simultaneous switching noise (SSN), Noise Margin(NM), voltage consumption forms a major issue due to increase in the clock frequency. The band-gap structures perform effectively with noise reduction and signal integrity. Planar band gap structures can be used to provide noise isolation in mixed signaling circuits and systems.

Non invasion detection and microwave sensing:

If the material is placed near to microwave near field probes, they can be used to sense the material properties if it lies in the vicinity of that probe. The increased size of the probe causes deeper penetration into the surface to be detected trading off the resolution. The paper [2] showed increase in the sensitivity of the probe without any compromise to its resolution feature. The evanescent field amplification can be achieved by using meta-materials was shown.

5. Case Study: Improvement In Gain Profile Of Patch Antenna

The research problem is design a micro-strip patch antenna with a natural dielectric with a relatively low relative permittivity and emanating radiation at a high microwave frequency. To test the problem for worst radiation considering the following design problem: dielectric constant 0.34 and frequency of 100 GHz. We have used a strip calculator GUI [3] to obtain the output parameters and the radiation pattern of the antenna which gives the following results:

Length(mm)	2.45328
Width(mm)	1.83254
Rad resistance(ohm)	36.0021
Efficiency	0.70549
Gain	8.41749
Char. Impedance(ohm)	125.251

Fig no.1: Calculated output parameters from strip calculator GUI.

The radiation pattern in E-plane and H-plane for the antenna is as shown in the figure drawn below:

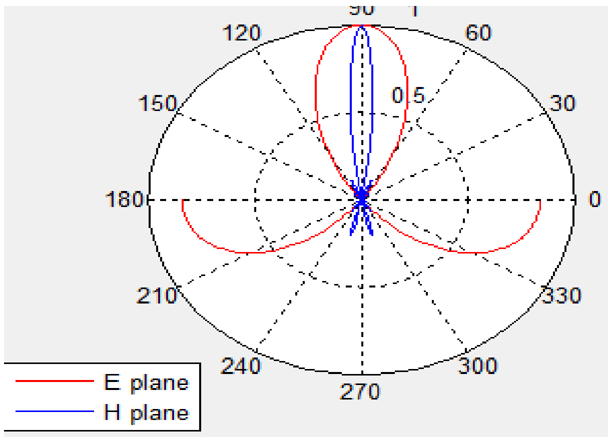

Fig no.2: The radiation pattern using strip calculator GUI.

The results obtained show that a dielectric material with lesser value of relative permittivity employed over a relatively high frequency becomes lossy as the oscillating dipoles are generated and the efficiency and gain of the antenna is reduced appreciably.

Now we consider a very practical example of microstrip patch antenna which is designed for IEEE 802.11 i.e. wireless LAN applications. The microstrip patch antenna is designed to be operated at 2.4 GHz ISM band employing MC Nylon substrate with relative dielectric permittivity 2.7 and thickness 0.35 mils. The frequency is varied from 2.0 GHz to 2.6 GHz in very small steps and the gain of the antenna is calculated.

This experiment shows that there is decrease in the gain of antenna by very small change in the frequency. As the frequency of operation in the microwave spectrum increases, the wavelength of the electromagnetic wave propagating through the device becomes approximately comparable to the dimensions of the circuit, the dielectric shows loss of electromagnetic energy due to oscillating dipoles, the loss tangent increases and the gain of antenna decreases

Frequency	Gain in dB
2.0GHz	20.22
2.1GHz	20.05
2.2GHz	19.81
2.3GHz	19.62
2.4GHz	19.43
2.5GHz	19.24
2.6GHz	19.08

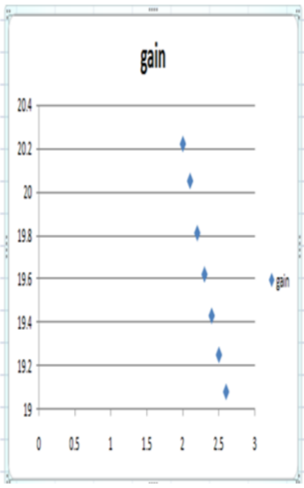

Fig no.3: Tabulation of results and graphical representation of gain

This can be mitigated by using a combination of patch and superstrate. The location of superstate is over a fixed distance from the patch. The paper [2] shows improvement in the gain of antenna by 4 dB at resonance frequency and the increase in efficiency by 17%.

The meta-materials show both positive permittivity and permeability because of which they can be used to absorb the EM waves generated over the surface of patch antenna

For this MSSR i.e. Magnetic Split Ring resonator can be used which is designed to have non-negative values of permeability and permittivity can be obtained at the resonance frequency of the antenna. The non-magnetic materials and electromagnetic band gap structures can be used to improve the gain characteristics but this does not show any significant and considerable improvement in the radiation of the antenna. The paper [2] states the low profile feature and gain of antenna both can be simultaneously achieved by using magnetic materials as superstrates instead of non-magnetic substances. The results in paper [2] is shown below.

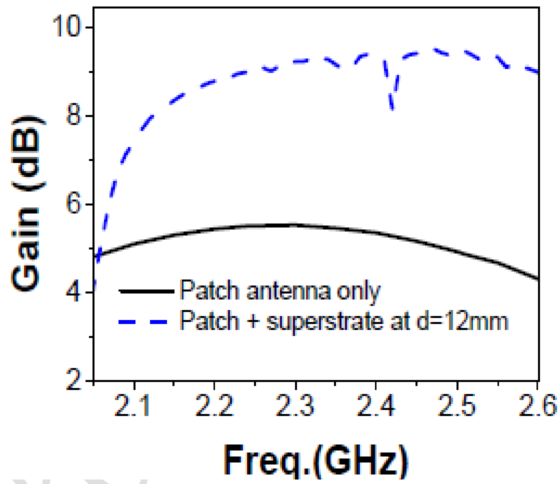

Fig no.4: Improvement in the gain profile of antenna [2].

6. Conclusion

The meta-material is as an emerging technology in the field of microwave and millimeter-wave wireless communication. The negative index materials, their properties is still under research and development of these materials in near future will find a very good place for them in the field of RF communication system design, electromagnetic engineering applications and much more

The development of chiral meta-materials and finding their use in different areas of applications is one of the hot researches these days. The gain and efficiency of the patch antenna can be significantly improved by using meta-material antenna superstrates. The future scope for research in this area is development of material with new properties and finding direction to use them in real time applications in electromagnetic engineering.

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