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Review

Metamaterials for performance enhancement of patch antennas: A review

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This review paper focused on the use of metamaterials for the performance enhancement of microstrip patch antennas. In this work, the definition of metamaterials used in literature is first reviewed and then we consider various challenging issues for the microstrip patch antennas. The paper hence concludes some thoughts on the future scope of research in the field of metamaterials, discussing the advantages that metamaterial based technologies offer compared to the conventional patch antennas.

Key words: Metamaterials, microstrip patch antennas (MSA).

INTRODUCTION

The 21st century was the beginning of a new era of materials called metamaterials that had dramatic impact on physics, optics, and engineering communities. Metamaterials also known as left handed materials (LHM) are artificially constructed materials that exhibit negative permittivity and negative permeability in a certain frequency range. In recent years increasing interest has been focused on the use of metamaterials for improving the performance of conventional patch antennas (Engheta and Richard, 2006).

Metamaterials are represented in terms of their medium properties, *viz*., DNG (Double negative -both ε & μ are negative), DPS (Double positive –both ε & μ are positive), ENG (Epsilon negative) and MNG (μ negative). Metamaterials found applications in various fields including sensor detection, remote aerospace applications, public safety, high frequency battle field communication, improving ultrasonic sensors, solar power management and for high gain antennas (Pendry, 2003; Raj, 2007). Veselago speculates that a material whose permittivity and permeability are simultaneously negative, such material if having any measurable degree of optical transparency, will refract an incident wave on the same side of normal rather than crossing it as shown in Figure 1. If the angle of incidence is still greater than the angle of refraction and assuming that the transmission velocity in the medium is lower than the free space velocity, the object may appear invisible to the observer (Sanderson, 2007). In October 2006, a metamaterial was created by US British team of scientists which rendered an object invisible to microwave radiations (http://www.dukenews.duke.edu/2006/10/cloakdemo.html).

VARIOUS ISSUES IN PATCH ANTENNA DESIGNING

The various challenging issues while designing a patch antenna are – reduction in size, directivity improvement, gain enhancement, bandwidth broadening and backlobe or sidelobe suppression. The key questions thus arise are: (a) How one or more of these performances can be enhanced using metamaterials? And (b) what type of metamaterial should be used to meet these requirements?

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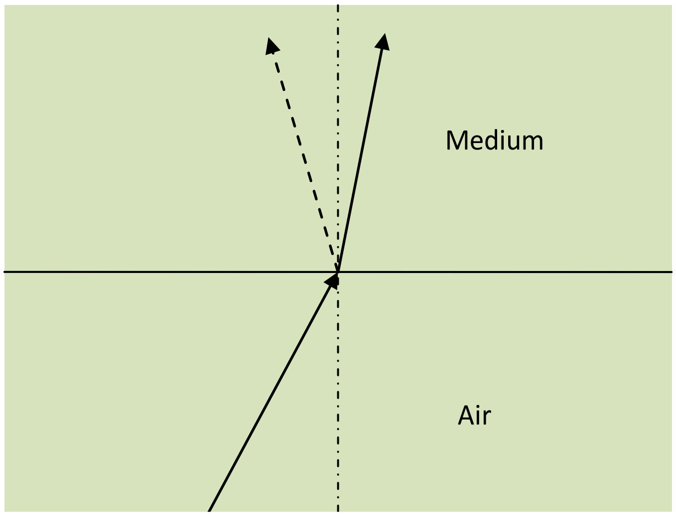

Figure 1. Conventional (solid) and metamaterial (dotted) refraction characteristics.

Surface wave propagation is a major problem in patch antennas that reduces antenna gain and efficiency, increases cross polarization, limits the bandwidth, increases end fire radiation, limits the applicable frequency range and hinders the miniaturization of patch antenna. Micromachining technology and photonic band gap structures are two solutions to the surface wave problem.

However, a quick literature survey shows that DNG Materials can be used for directivity enhancement, radiated power enhancement, antenna performance improvement and bandwidth enhancement.

Directivity enhancement

Veselago first introduced DNG materials and demonstrated that a slab of DNG material would act like a lens and it would, thus focus the energy emanating from an antenna (Smith et al., 2000). Metamaterial has inherent property that controls the direction of electromagnetic radiation, in order to collect the emanating energy in a small angular domain around the normal to the surface (Figure 1) A slab of DNG material would improve the directive properties of an antenna than other diffraction-limited systems, such as a convex lens made with a conventional DPS material (Veselago, 1968; Pendry et al., 1999; Pendry, 2000).

Radiated power enhancement using DNG

With the application of the conventional techniques, such as photonic band gap materials an increased amount of radiated power couples to the space wave (Stefan et al., 2002). Surface wave coupling effects are also absent. The power radiated by a small antenna can be increased, through the application of DNG metamaterial (Stefan et al., 2002). When the small dipole antenna is surrounded by DNG metamaterial, an increase in radiated power by more than an order of magnitude over free space antenna is obtained (Steve, 2006). The decrease in the reactance of dipole antenna corresponds to the increase in the radiated power.

Antenna performance improvement using Split Ring Resonators (SRRs)

It was demonstrated that the monopole-SRR metamaterial antenna operates efficiently at λ/10 (antenna size) using SRR-wire configuration. Good coupling efficiency and radiation efficiency are thus obtained. The operation of monopole SRR antenna was found to be comparable to the conventional patch antenna at λ/2 (which is recommended as an antenna size for efficient coupling and radiation for patch antenna), (Ziolkowski and Allison, 2003) thus it can be used wherever patch antennas are used.

Monopole-SRR antenna becomes an acceptable small antenna at the resonance frequency of SRR. When compared to the conventional monopole antenna, when SRR configuration is added, the characteristics such as radiation pattern are changed. SRR structure employed in the antenna can be modified to obtain an antenna size of about λ/40.Furthermore, by coupling 2, 3, and 4 SRRs a slight shift in the radiation pattern is observed (Mittra, 2007).

Bandwidth enhancement

Metamaterials have been shown to enhance specific parameters of low profile and high profile antennas. Metamaterials can be used as covers to increase the bandwidth of printed patch antennas. An example for broadside radiation is metamaterial based planar leaky wave antenna.

Such an LWA antenna consists of a metamaterial layer with positive or small values of permittivity and permeability placed on the ground plane and is suitable for producing a narrow beam of radiations at broadside. The directivity increases significantly as the permittivity (or permeability) of the layer decreases (Kamil and Ekmel, 2007).

DEVELOPMENT AND APPLICATIONS

W.E. Kock developed the first metamaterial in the late 1940s. Up to 2002, the metamaterial structures were impractical for microwave applications owning to narrow

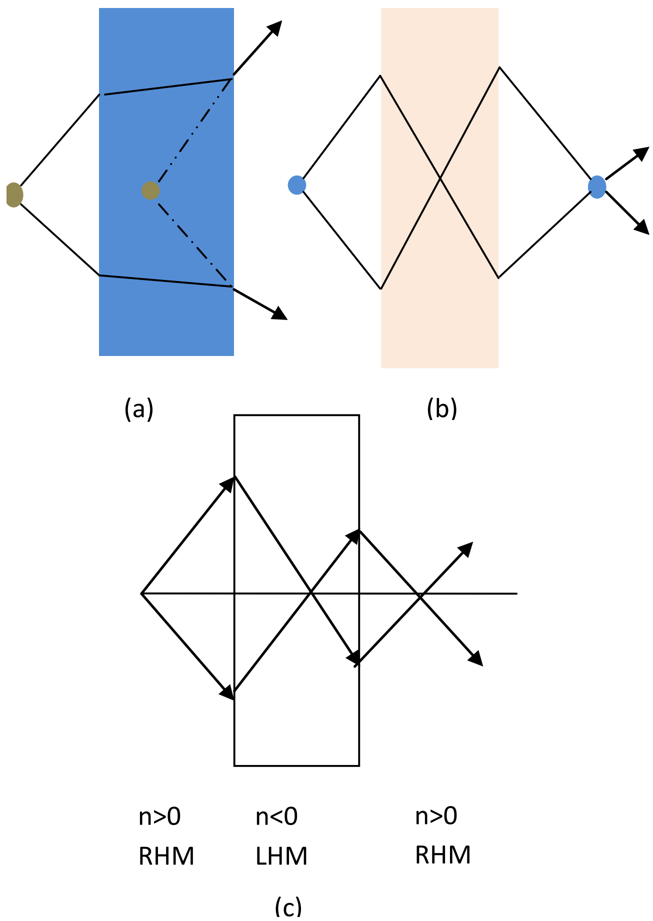

Figure 2. (a) Perfect reconstruction (b) high transverse wave vectors imaginary longitudinal component evanescent fields and (c) perfect lens.

bandwidth and low transmission coefficient (Oliner, 1993; Kock, 1946). The various developments include perfect lens and use of metamaterial slab as a cover or as a substrate.

Perfect lens

John Pendry first postulated that a negative index material would enable a perfect lens because of the property that a wave propagating in LHM exhibits phase advancement instead of phase delay. The superlens is an optical lens which exceeds the diffraction limit but does not rely on negative refraction. The first superlens demonstrated at microwave frequency provided three times better resolution than the diffraction limit as shown in Figure 2. In 2008, two major developments were reported in superlens research and these are:

1. Alternate layers of silver and magnesium fluorides were deposited on the substrate. The nano grids in the layers provided a 3-D structure with a negative refractive index in near infrared region.
2. Metamaterial from silver nano wires deposited in porous aluminium oxide was formed. This provided negative refraction below 660 nm (Kock, 1949).

The perfect reconstruction through a metamaterial is shown in Figure 2a. Figure 2b and c shows that for a LHM the waves are refracted in such a way to produce a focus inside the material and another just outside. It leads to the creation of highly directional antennas.

Metamaterial as cover

The unit cells of metamaterial can be combined into a slab to build up a metamaterial cover. A new patch antenna with a metamaterial cover was proposed in 2005, which resulted in enhanced directivity (Chemical and Engineering News, 2008). According to the results, the directivity of patch antenna with metamaterial cover is significantly improved compared to conventional patch antennas. This was cited in 2007, that using metamaterials, efficient design of directive patch antenna can be produced (Fang et al., 2005).

Other applications

It has been demonstrated at National Institute of Standards and Technology that thin films of metamaterials can reduce the size of the resonating circuits that generates microwaves (Said et al., 2005). Agile antennas have been designed using metamaterials. It has been postulated that because of the subatomic properties of metamaterials, they could be built to bend matter around them. For example a matter cloak could be used to bend a bullet around a person instead of absorbing it. This approach is similar to bullet proof vests (Fang et al, 2005).

ON-GOING PROJECTS

Miniaturized nano- optical devices

An international group Metal Structure for Plasmonics and Nanophotonics aims at developing a new miniaturized nano- optical device based on Plasmonics structures as well as studying the propagation properties of surface plasmons (Pendry et al., 1998).

Metamaterial radome designs

Naval Systems Air Command (Navair) is an international group which is applying the concept of metamaterials to improve the performance of radome antenna designs (Alu and Engheta, 2005).

Antennas with high operational frequency

U.S. Army Research office is working on development of a tunable antenna, capable of operating at high-frequency (30 to 100 GHz) along with GHz Electromagnetic wave Science and Devices for battlefield communications. California and Colorado Universities also collaborated with this project (Smith, 2005).

High gain antenna applications

The National Geospatial-Intelligence Agency is performing an experimental study on coupling a radiating element with a lens so as to obtain a high-gain antenna. The negative index lenses have shown to possess a much lower geometrical aberration profile as compared to the positive index lenses (http://people.ee.duke.edu/~drsmith/collaborators.htm; Air force office of scientific research (AFOSR).).

DISCUSSION

Researchers studied the different parameters of microstrip patch antennas such as gain, directivity and bandwidth and the use of metamaterials to improve these antenna parameters. For the improvement of directive gain unit cells of omega structure are combined to form a slab which is used as a cover over conventional patch antenna. The conventional antenna without cover has maximum directivity of 8.271 dBi while the antenna with cover has directivity of 11.5 dBi (Ahmad et al., 2010).

Merih et al. (2009) proposed a broadband microstrip antenna based on metamaterials. The proposed antenna has a maximum gain of -1 dBi at 2.5 GHz and a 63% bandwidth over the band of 1.3 to 2.5 GHz.

Ziolkowski and Erentok (2006) demonstrated that electrically small antenna system can be formed by combining an infinitesimal electrical dipole with ENG spherical shell. Such systems were made to be resonant with a large enhancement of the radiated power in comparison to the antenna alone in free space.

Erentok and Ziolkowski (2008) proposed metamaterial inspired efficient small antennas. The proposed EZ antennas are shown to be naturally matched to a 50 ohm source without matching network. It is demonstrated that EZ antennas have high radiation efficiencies with good impedance matching.

Farad et al. (2005) proposed a compact and low profile metamaterial ring antenna using two unit cells. The antenna offers a 120 MHz -10 dB bandwidth and an efficiency of more than 50%.

All the researchers here premeditated various methods for the improvement of various antenna parameters. Heading in the direction of their aim they achieved the improvement in various antenna parameters using various methodologies.

FUTURE CHALLENGES

Several challenges must be surpassed before metamaterials make the transitions from theoretical investigation to practical applications in the high frequency regions (visible, IR, THz).

One of the major limitations of metamaterials is their typically narrow band response. The limited bandwidth of metamaterials limits their application in negative-index in the whole visible spectrum.

Moreover, within the next few decades, metamaterial research at microwave and radio frequencies is expected to improve the antenna designing by reducing the antenna size and better performance for satellite antennas and personal mobile devices (Holloway et al., 2008).

SUMMARY

From this survey, it is clear that metamaterials can be used for improving the performance of conventional patch antennas. In this paper we have taken a brief look at current work and development in the field of metamaterials. We also examined the on- going projects on metamaterial to enhance the performance of antennas. Various future challenges are also considered.

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