Term Paper: Metamaterial-Based Antennas

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1. Introduction

Metamaterials are artificial materials with unusual properties that are not found in naturally occurring materials, and have engineerable dispersion relations, permeability, and permittivity [1]. These structures have a lower resonance frequency than the traditional antennas, allowing for antenna miniaturization and desirable radiation properties, as well as establishment of circular polarisation. By suppressing surface waves, metamaterial loading also improves isolation between antenna elements in multiple-input-multiple-output (MIMO) systems [2]. This paper [3] looks at the developments in metamaterial antenna design of late.

2. Motivation

Rapid technological enhancements in the electronics industry has made compact antennas with high bandwidth and gain a necessity. In a bid to enhance channel capacity, multiple such antennas per device would be needed at the transmitter and receiver. Numerous strategies have been tested to enhance antenna performance in the past few years including the usage of metamaterials in antenna design. These materials' adjustable features enable the design of efficient antennas, filters, and microwave devices that are not possible with conventional antennas.

3. Body

Antennas can broadly be categorized into two classes: leaky wave antennas and resonator-type small antennas.

3.1. Leaky Wave Antennas (LWAs)

Standard leaky wave antennas only have forward-scanning capabilities, that is, only half-space can be scanned at a time. Implementing classic LWAs with metamaterials with the use of composite right/left handed (CRLH) transmission line enables even backward to forward beam scanning that permits scanning in all directions.

3.2. Resonator-type small wave antennas

These are broadly classified into the following categories:

3.2.1. CRLH based antennas

These antennas are based on microstrip technology, which has unit cells that have a waveguide structure. The resonant frequencies of the circuit can be manipulated by designing a dispersion curve, but due to the size considerations, these antennas are mostly made for negative or zero order modes. The flexible dispersive relations enable useful properties such as zero order resonance which can lead to infinite bandwidth. This is profound because it implies physical sizes would be independent of frequency, which can result in miniaturization of antennas and can match the radiation patterns required.

3.2.2. SRR based metaresonator antennas

Split Ring Resonators (SRRs) are magnetic dipoles can bring the desired magnetic response in the metamaterials by creating a very strong magnetic coupling. In a proposed design of an antenna of this type, the SRR and monopole antenna are electrically excited together via an

inter-digital capacitor that can store electric energy. The combination of these elements generates a uniform surface current distribution which increases efficiency due to the complete usage of the spherical space around it.
Complementary Split Ring Resonators (CSRRs) are the duals of SRRs, in which instead of the strong magnetic polarizability appearing in the SRR, a strong electric polarizability is generated instead. Using CSRRs, antennas with various types of polarizations, such as identical or orthogonal, can be generated.

3.2.3. Antennas loaded with metasurface

The design of these antennas is as follows: a small radiating strip is surrounded by an artificial magnetic conducting surface, which together act as a perfect magnetic conducting surface. A partially reflecting surface in combination with this structure, placed at a quarter wavelength distance creates a uniform radiation on the aperture, which behaves as a high gain antenna. The metasurface not only leads to higher gain and a superior radiation performance, it can also store electrical/magnetic energy and lead to smaller antenna sizes and better bandwidth.

4. Novelty of the work

Conventional antennas are vastly inferior to metamaterial antennas, since the latter have desirable properties such as small physical dimensions, better efficiency and broader bandwidth. For standard antennas, quality factor and radiation loss are inversely proportional to the size of the antenna. Metamaterial antennas provide a way to alter the dispersion relations, which can achieve reduction in size of antenna while also maintaining good radiation performance.
The paper reviewed [3] investigates various metamaterial antenna topologies, and the associated advantages and challenges. It also suggests methods to overcome a few limitations of metamaterial based antennas, such as using planar patterned metamaterial concepts to increase bandwidth and mentions metamaterial properties required to achieve higher radiation efficiency.

5. Future directions of this work

Physical realization of metamaterial antennas: Many new designs of metamaterial antennas rely on low loss homogeneous metamaterials, which are not fully physically realizable yet.
Tradeoffs: Another challenge is managing to have high bandwidth and high efficiency along with small antenna size. While size isn't a problem here, the dichotomy between bandwidth and efficiency still persists, an area with huge scope for potential research.
Superlens: Focusing beyond the diffraction limit is theorized to be possible with a lens made of metamaterials. Sub-wavelength imaging means that it would be possible to see entities smaller than wavelength of light, such as atoms and molecules. As of now, there are still many obstacles in achieving sub-wavelength resolution.
Transformation optics: This is the application of metamaterials to manipulate optical properties at will, which can be used to engineer electromagnetic "illusions" such as making objects appearing as invisible. This opens up vast applications in defense and stealth technology, such as enabling perfect camouflage of military objects. Although near perfect cloaking has been achieved already in the microwave spectrum, invisibility in visible spectrum has not yet been achieved due to shorter wavelengths.

References

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3. Dong, Yuandan and Itoh, Tatsuo, "Metamaterial-Based Antennas" Proc. IEEE, **100**(7), 2271–2285 (2012).