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Field propagation of a metallic grid slab that acts as a metamaterial

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Abstract

A metallic grid slab has been shown to work as a novel metamaterial which can shape the divergent field emitted from an embedded monopole microwave antenna into a directive transmission at a specific frequency. The transmission of such subwavelength slab remains an issue of challenge. In this work, we experimentally investigate the transmitted behavior of such subwavelength grid slab to explore the underlying mechanism of wave propagation. It is found that there is a large tolerance of directive emission even with a tilted slab. The deviation along the directive emission direction is analyzed based on the interference theory.

Keywords: Metamaterials; Left-handed materials; Directive emission

1. Introduction

The original work of left-handed metamaterials (LHM) can be traced back to Veselago who explored the consequence of the simultaneous occurrence of negative permeability and permittivity [1]. Since his work in 1968, left-handed metamaterials have attracted lot of interests. Substantial progress has been made, mainly because of the works of Pendry et al., and other research groups [2–8]. A combination of simultaneously negative ε and μ can cause many intriguing properties such as negative Goos–Hänchen shift [9], reversed circular Bragg phenomenon [10], photon helicity reversal [11] and unusual quantum optical effects [12]. One of the most remarkable applications of LHMs is perfect lens [13]. Until recently many experiments were performed to test this as a theoretical hypothesis, and a large number of successful reports were contributed [2–8] to prove the existence of metamaterials with a negative index of refraction. In 2000, Pendry proposed a superlens of negative index refraction in order to break diffraction limits under certain conditions [13]. After that, not only an experimental demonstration of this superlens in microwave range was published [14] but also other forms, different from a split ring resonator (SRR), were also demonstrated [15,16]. In order to understand the optical properties of the LHM slab, the finite difference in time domain (FDTD) method is often used to numerically emulate the propagation phenomenon. For example, Loschialpo et al. reported the FDTD snapshots of the magnitude of the electromagnetic field propagating from a divergent source [17]. These works also have helped to stimulate the general interest of metamaterials in the community.

Not only structures with a negative refractive index attract a lot of attention, metamaterials with an effective index of refraction between 0 and 1 draw many interests as well, even though they are not as popular as LHMs in the literatures. Enoch et al., working in the microwave domain, proposed a metallic composite material which allowed an embedded monopole electromagnetic wave source to have its emission field limited in a narrow angular distribution, called directive emission [18]. Their experiment showed that a metallic grid slab acts as a metamaterial with an effective refractive index less than unity. That directive emission is quiet interesting and is understood intuitionally on the basis of Snell's law with the refractive index less than 1.

Instead of a follow-up of the study, we focus on investigating the propagating behavior of electromagnetic wave through

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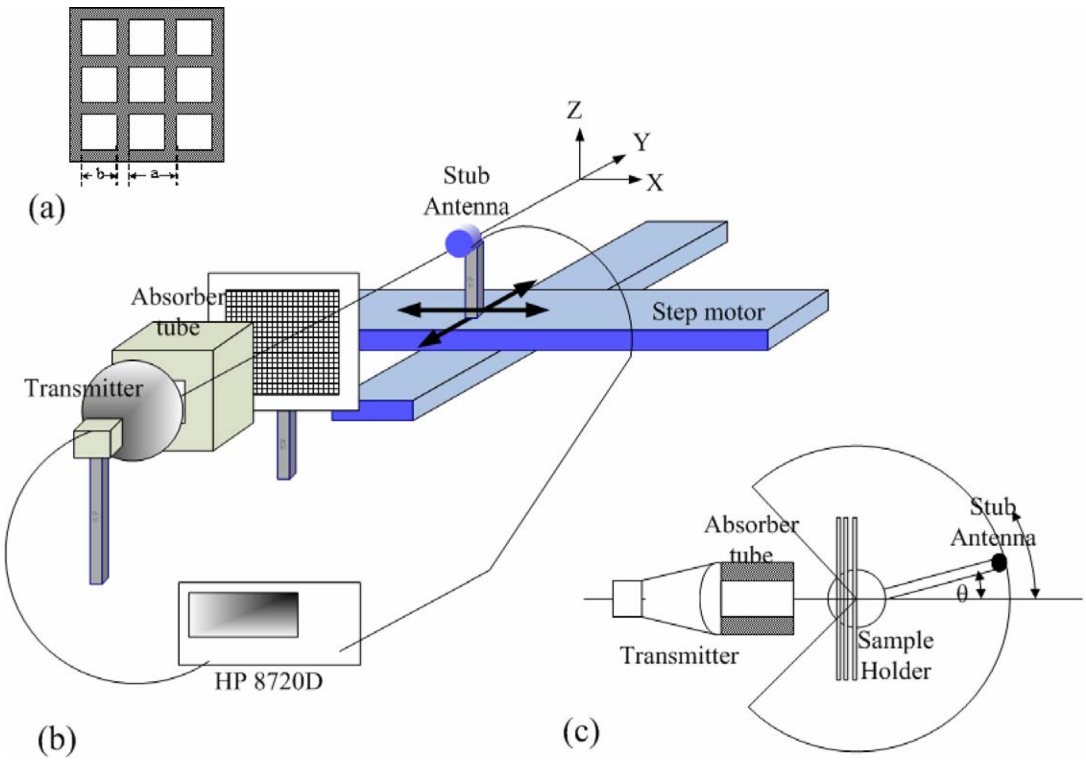

Fig. 1. (a) The schematic diagram of a metallic grid where $a = 5.8$ mm and $b = 4.85$ mm, and the distance between slabs is 6.8 mm (not shown in the diagram). (b) The layout of the experimental setup. This configuration uses 2 linear step motors to analyze the two-dimensional electric field distribution. (c) The alternative configuration is designed for measuring the angular distribution of the electric field.

such subwavelength metallic grid slab. In this Letter, we use a composite metallic grid slab as our sample to experimentally explore these novel features. Experiments are carried out using microwave beams, allowing us to deduce extensive results due to the different incident aspects. These results may provide a possible explanation and help us to understand the mechanism of the interaction between the incident microwave and the metallic pattern. The methodology we manipulated in this Letter is replacing the embedded monopole source by a collimated external transmitter owing to the intention of observation of propagating path of the passing electromagnetic beams. The main purpose is not to demonstrate directive emission but to explore the way that electromagnetic beam propagates and the underlying mechanism. A simple and effective model will be provided in this Letter to explain how the electromagnetic beam travels inside the medium on the basis of interference principle. The Letter is organized as follows: in Section 2, the characteristics of the sample and measurement method are summarized, while in Section 3 we presented the experimental results. Final section is the conclusion.

2. Materials and experimental method

The metamaterial is composed of copper grids made by using the conventional printed circuits technology of electronics and the thickness of copper slice is about 0.1 mm, then is coated on the printed circuit board (PCB) whose thickness is 1 mm. Six identical grids with a square lattice whose pitch is 5.85 mm comprise the structure of sample with the separating distance, $d = 5.88$ mm, and the opening square of each unit cell is 4.9 mm × 4.9 mm, as shown in Fig. 1(a). An Agilent vector network analyzer (VNA), HP8720D (frequency range 0.05–20.05 GHz), is utilized for the transmission spectrum analysis and the spatial electric field measurements. A lens-horn antenna (FLANN 16810-FA) driven by the VNA is used to produce the z directional linearly polarized microwave, propagating along the y direction. A tiny radio frequency (RF) stub antenna (HERLEY 845CX-10) is regarded as the microwave receiver to analyze the detailed spatial field distribution. The physical size of the detecting area of this stub antenna is around 1 cm × 1 cm and it works well within the experimental frequencies region (10 to 17 GHz). The sample holder is capable of rotation driven by a rotary motor and its movements can be controlled by a personal computer. In order to prevent the noise reflected from the environments, a microwave absorber is used to surround the entire experimental system. The detailed schematic diagrams of experimental layout are shown in Fig. 1(b) and (c).

Despite taking a lens-horn antenna as the microwave transmitter, the produced electromagnetic field disperses with the propagating distance through free space due to its nature. In order to ensure that the incident electromagnetic wave acts as a collimated beam when penetrating through the metamaterial, the sample is not allowed to be placed too far away from the transmitter. The function of the rectangular tube made of microwave absorbing material is helpful to filter off the outer region of the produced microwave which is originally emitted by a larger angle. The opening of the tube is about 7.5 cm × 7.5 cm and its length is 20 cm. The resultant propagating electromag-