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Combination of artificial materials with conventional pyramidal absorbers for microwave absorption improvement

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ABSTRACT

This article addresses the combination of an artificial and conventional absorber materials in order to enhance its absorption properties and compactness. We demonstrate an increase of the absorption performance of the pyramidal absorbers by integrating a metamaterial layer. The latter is composed of two unit cells with multi resonance behavior between 2 GHz and 18 GHz. The simulation results of the hybrid material predict absorption for normal and oblique incidence of the electromagnetic wave at low and high frequencies depending on the wave polarization.

Hybrid materials (metamaterial + conventional pyramidal absorbers) have been achieved using two pyramidal absorbers; the first one is a commercial absorber APM12/SIEPEL and the second one is the same material but with reduced dimensions. These absorbers are made of polyurethane foam loaded with carbon particles. The measurements show an increase of the absorption performance compared to the pyramidal absorber alone, even for the absorber with reduced dimensions.

1. Introduction

The design of resonant metamaterial absorbers has attracted intense attention in the last few years [1–4]. The design idea of this Microwave Material Absorber (MMA) is to adjust the effective permittivity $\varepsilon_{eff}(\omega)$ and permeability $\mu_{eff}(\omega)$ independently in order to match the effective impedance of the MMA to the one of the free space. This adjustment is made by varying the dimensions of the electric resonant component and the magnetic resonant component in the unit cell. By this match, a large resonant dissipation is achieved, thus, wave transmission and reflection are minimized simultaneously, and absorption is maximized [5].

Compared with conventional absorbers, the MMAs exhibit some advantages including the ultra-thin thickness, lossless surface, simple as well as light configuration and easily extendable absorbing frequencies [6,7]. Different designs of metamaterial absorbers are proposed and studied in literature. For example, the E-shaped dielectric resonators, proposed by *Li and al*, work at normal and oblique incidence in between 0° and 70° and present absorption higher than 0.7 in the frequency range between 13 GHz and 14 GHz [8]. A very simple shape of metamaterial, composed of rectangular metal tabs, was proposed by *Yoo and al* and presents multiple absorption ranges around four different resonant frequencies [9]. A multilayer metamaterial absorber was also studied [10]. This broadband metamaterial absorber shows a good absorption coefficient between 8 GHz and 14 GHz [10].

Otherwise, it has been demonstrated that the inclusion of Frequency Selective Surfaces (FSS) in the pyramidal absorbers can significantly improve the absorption performance [4,11]. The theoretical study of the inclusion of the metamaterial on the top of a truncated pyramidal absorber shows a decrease of reflection loss at high frequencies (between 15 GHz and 20 GHz) [4], while the incorporation of the metamaterial inside the base of the pyramidal absorber shows an optimization of the reflection loss for low frequencies (between 1 GHz and 5 GHz) [11].

In the present study we have tried to enhance the absorption performance of the conventional pyramidal absorber in a large frequency band (between 2 GHz and 18 GHz) and for normal and oblique incidences of the electromagnetic (EM) wave. For this, we have used a combination of a metamaterial absorber with a conventional absorber, used usually in anechoic chambers; the idea is to enhance the compactness of these anechoic chambers. The study of the hybrid absorber materials (metamaterial + commercial pyramidal absorbers) was done using the classical pyramidal absorber backed with a metamaterial array composed of two unit cell resonators (interleaved snake and spiral shapes). A

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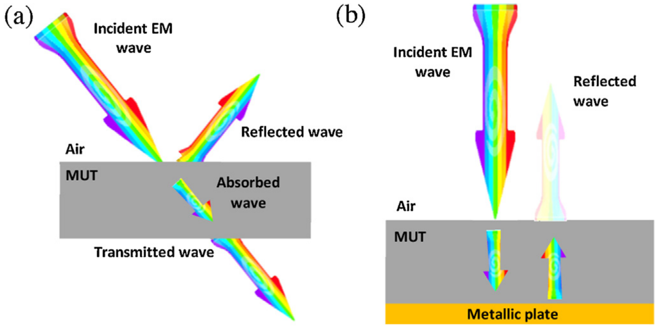

Fig. 1. (a) Reflection/Transmission mode configuration and (b) Reflection mode configuration for a normal incidence of the wave.

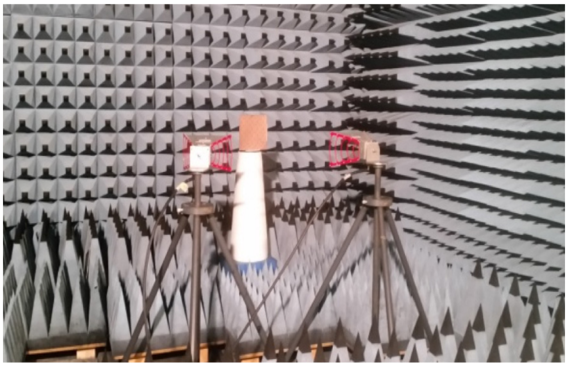

Fig. 2. Measurement setup for samples in anechoic chamber for the oblique configuration.

simulation study of the hybrid material was done using the CST Microwave Studio software. These simulations are compared to the measurement results of the achieved prototypes of the hybrid materials.

This paper is organized as follows: in the next section, the characterization method and the used configuration are detailed. Section 3 presents the designs of the two unit cells and of the interleaved metamaterial array (combination of the two cells). The simulation and the measurement results of the reflection coefficient parameter of these different structures are shown. The hybrid materials achieved using two different pyramidal absorbers backed by the metamaterial array are described in Section 4; the preliminary simulations and the measurement results of the prototypes, for different incidence angles and different polarizations of the electromagnetic wave, are presented and discussed. Section 5 concludes this paper.

2. Configuration and free space characterization method

Usually, for electromagnetic wave/material interaction, the material under test (MUT) can be modeled as a flat surface surrounded by air (Fig. 1a). A plane wave in a large frequency band is generally used to simulate this interaction. Fig. 1a presents the visualization of the behavior of the EM wave when encountering the MUT. Any material with a thickness of $\lambda/4$ will resonate. The incident EM wave will be partially reflected at the top surface of the material (interface air/MUT) and the other part will be propagated through the MUT. The later will be partially absorbed inside the material and the rest transmitted through the MUT. The reflection coefficient is defined as a ratio between the reflected electric field and the incident electric field at the surface of the material. The transmission coefficient is defined as the ratio between the electric field after the second interface (MUT/air) and the incident electric field. If the material has a metallic plate (MP) placed at the bottom (Fig. 1b), the wave will propagate through the MUT and when it encounters the metallic plate it will undergo a total reflection at the interface MUT/MP and will propagate back to the first interface of the material (air/MUT). A part of this reflected wave will emerge from the MUT and can be detected.

For an absorber material, the transmission and reflection of the wave through the material have to be minimized simultaneously, and the absorption maximized. For this, the measurement of the reflection and transmission coefficients is necessary in order to characterize the absorption performance of materials. This performance can be also characterized by the measurement of

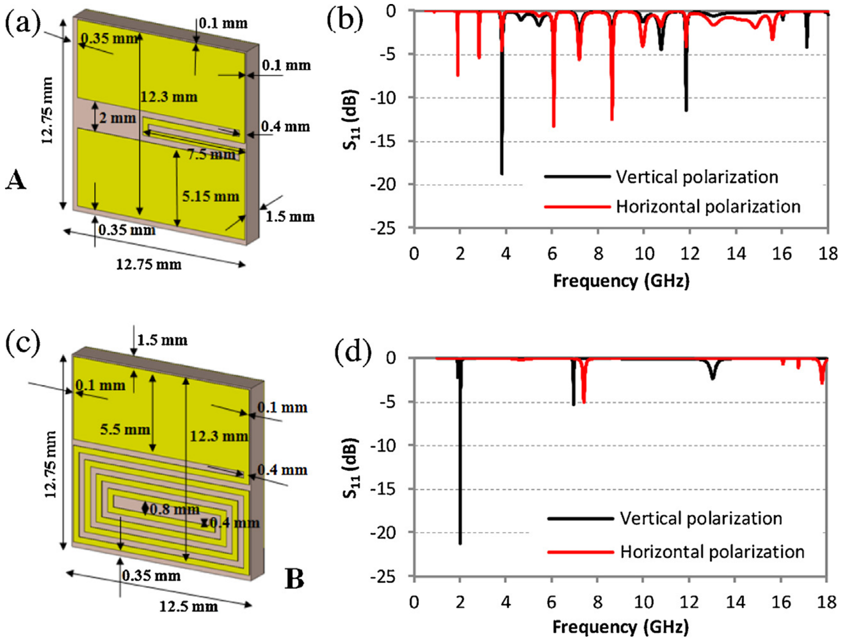

Fig. 3. (a) Design and (b) reflection coefficient of the first (referred A) metamaterial cell and (c) design and (d) reflection coefficient of the second (referred B) metamaterial cell for a normal incidence of the wave.