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Original research article

Sensory applications of resonator based metamaterial absorber

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ABSTRACT

Metamaterials are attractive media for scientific society for their potential multi-functional and a wide range of applications due to their unusual electromagnetic properties. In this paper, we present several important applications including pressure, density and volumetric moisture sensing based on rectangular split ring structure with a strip line. These applications are carried out experimentally and numerically. Since the sensing ability is mostly connected with the resonance frequencies, we have carefully selected a frequency range where the resonance shifts occur linearly depending on the pressure and the density of the medium or material to be tested. The proposed model can be used for chemical, agricultural, medical and biological sensing applications in the microwave frequency band. The model is composed of a split ring resonator (SRR) topology and the sensing layer sandwiched between the SRR and a rectangular copper layer located at the background. Middle-sensing layer changes its dielectric behavior linearly depending on the pressure and the density allowing us to determine the unknown values of these parameters.

1. Introduction

Veselago's study on Metamaterials (MTMs) in 1968 [1] showed that both negative permeability and permittivity values can be obtained simultaneously with these periodic structures [2–4]. These new materials opened a new area and offered exotic and unusual features to the science community which cannot be readily found in nature. Metamaterials with their extraordinary electrical and magnetic behaviors offer a wide range of application areas, such as sensing, absorption, polarization rotation, source shifting or imaging, perfect lenses and many more applications attracting an increasing number of researchers in this field [5–9].

In the case of sensing applications, micro and nano size metamaterial structures started to be built with the new and continuously growing technology [10–15]. In this study, we have investigated a pressure and a density sensing ability of a metamaterial absorber (MA) both numerically and experimentally. The key parameter here is the resonance frequency (or frequencies for multiband structures) of the metamaterial structure. This frequency changes depending on the environmental parameters which is density and pressure in our case. These parameters change the resonance frequency location allowing us to monitor the variation of them in a very precise way. An effective sensor must meet some important requirements. One of the most important requirements is the linearity. In other words, the structure should give a linear response with a linearly varying pressure or density parameters or any

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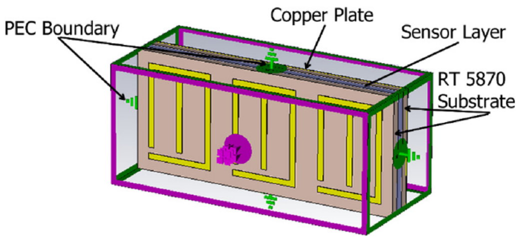

Fig. 1. The proposed MA based sensor design.

parameters you are monitoring. Therefore, we have carefully designed the proposed structure and chosen the working frequency range as well as the substrates in order to meet this criterion. Other requirements can be listed as low loss factor, having a measurable signal depending on the variation of the parameter in question, sensor sensitivity and durability that we have considered for the proposed design.

Another exciting and interesting application of our design is the Electromagnetic Harvesting. It is clear that the new possible energy sources are the first priority of all scientific worlds. Promising results in Electromagnetic Harvesting studies are encouraging the new studies in this new field. With a small configuration in our structure that includes filling the sensing layer with AD350 and adding a resistor with the value of 1500 Ω in a gap between the patch and the rectangular copper frame around it, we have successfully obtained a considerable amount of harvested power. This extra feature gives the structure a multifunctional property comparing with the similar studies in literature.

2. Numerical design & experimental setup

In this study, we created a MA based sensor. The proposed design consists of a Roger RT 5870 type dielectric material which has a thickness of 0.76 mm and a dielectric constant of 2.33 which is chosen as a substrate as seen from Fig. 1. The suggested structure has five parts, resonators, a substrate, sensor layer, another substrate and a copper plate, respectively. Back side of this sensor design is completely plated with copper type metal which is supported by an RT 5870 material. In numerical analysis, PEC boundary conditions for x- and y-directions and open boundary condition for z-direction are applied to simulate waveguide measurements. Sensor layer is realized in order to use for multi-functional applications. It can be adapted for different sensor applications such as density, pressure, temperature and humidity sensing. In this study, density and pressure sensor applications are numerically and experimentally realized and discussed. In Fig. 1, the proposed MA based sensor design and waveguide boundary conditions are given.

In addition, the dimensions of the MA based sensor are given in Fig. 2. The novel geometry of the sensor is designed according to the numerical study results and it has unique properties comparing to the other studies in literature. Resonator part has three identical split ring resonators which have individual patches inside. This design is increasing the coupling effect of the resonators which is directly related with the sensitivity accuracy level for various sensor applications and taken into account in this study. The dimension of the unit cell is compatible for X band waveguide and the resonators have a width of 0.5 mm, while the gap between the resonators and side wall of the substrate is 1 mm. S – Parameters, as shown in Fig. 1 are measured by using a waveguide. For waveguide boundary measurements, the produced samples are placed in a front face of the waveguide WR90 with the dimensions of 22.86 mm × 10.16 mm. Measurements are realized by means of Agilent N5234A PNA-L Microwave Network Analyzer, X281A Coaxial Waveguide Adapter (Probe coupling), and WR90 waveguide. WR90 waveguide operation frequency is between 8 GHz to 12.4 GHz. The experimental setup is illustrated in Fig. 3.

3. Metamaterial absorber based sensor applications

In this part, density and pressure sensor applications are given in detail. In addition, this design can be used in other sensor applications as well when the sensor layer is filled with a related material. Related material can be chosen according to the parameters to be detected such as moisture or temperature. When the dielectric constant of the related material changes according to the environmental parameters, it is going to affect the overall reflection coefficient which is desired for the related sensor applications.

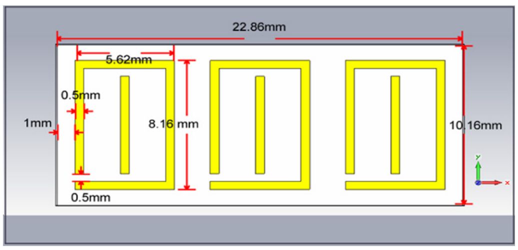

Fig. 2. Dimensions of the suggested MA based sensor design.