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Perfect Metasurface absorber for microwave applications

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Abstract

This design provides two absorption band with an absorption capacity of 99.98%. In this study presents analytical results using the CST program for a very simple design of an electromagnetic wave absorber with a negative refractive index, a copper X-shape printed on an insulating layer separating it from a flat ground layer of copper. This absorption is due to the dipole oscillation. Also, controlling the shape dimensions and thickness of the insulating layer leads to good results in the synthesis of the resonant frequency that contributes to the applications of energy collection and protection from the effects of electromagnetic waves. The results gave the highest value of absorption with h = 1 mm) and by selecting a proper value for g = 1 mm, the proposed design obtained the good absorption results. It is also worth noting that the design can be developed to operate in a wide range of frequencies such as microwaves, terahertz, up to optical frequencies, which may contribute to potential applications in many engineering and optical technologies.

Introduction:

Materials with supernatural properties or metamaterials are materials with ideal properties (in the spectrum of electromagnetic waves) and with an infinitesimal cell size compared to the wavelength, it take attention of scientist due to its special properties such, Ideal lenses [2], negative refractive index [3] back word wave [4] split ring resonators [5], nonlinear phenomena [6] lattice structure [7], perfect absorber [8] clocking [9] , background waves [10], and many more other structures have been suggested in the literature to achieve the electromagnetic properties of materials with super properties [11]. Most of the structures proposed for metamaterials depend primarily on a metal resonator that fluctuates greatly within the design frequency range with large energy losses that are never inevitable which negatively affect its performance. On the other hand, these losses play a fundamental role in optical frequencies.

The world witnessed the first perfect absorber in 2002 by Landy et al.[12], with an absorption capacity of 88%. It consisted of a separate loop and a separated wire by an insulating substrate [12]. Also, in 2008, they demonstrated an ideal absorption of electromagnetic waves using a carefully engineered interconnected structure [13]. Since then, ideal absorbers based on metallurgical material technology have received a large amount of attention, and numerous engineering designs have been proposed in this field [15,14]. This effort is due to its ability to achieve 100% absorption of electromagnetic waves due to its importance in many applications such as spectral detection, phase determination, thermal imaging, accurate thickness gauge, and solar cell applications. It is very difficult to find natural substances with an ideal absorption capacity to develop an absorber to generate a very high value in the terahertz frequency band. This absorber can be used in airport security systems, imaging systems, thermal detectors, and more [26,27]. The need for absorbers that operate in the microwave package increases due to the importance it carries in reducing interference in radars, collecting energy, using it in wireless charging, and hiding from detection in the military industries, sensors, and others. Great efforts have been made to achieve the ideal absorption of electromagnetic radiation in gigahertz limits. For example, Hampotur et al. [16] achieved a single beam absorbance with an absorption rate of 98%. Landy et al. [17] obtained an imperceptible absorption polarization with an absorption rate of 77%. Skolokov [14] showed a single absorption with a wide polarization angle. Unfortunately, all of these efforts share a weakness, which is the narrow width of the absorbed wave packet that greatly hinders practical applications. Later on, some methods were followed to develop the absorption beam or multiplexed absorption beam with gigahertz boundaries such as two- and three-beam absorbers [18,19]. Also, some efforts have worked on developing broadband absorbent materials by stacking multiple layers of metal resonators within a single cell [20,27].

However, in many cases, the narrow-band absorber is essential for spectroscopic imaging and sensors. Unfortunately, the absorption of narrow-band materials shares some disadvantages. First, the absorption performance of the proposed design is sensitive to the polarization of incident waves that greatly impede scientific applications. Second: The uneven surface of the structures makes it very difficult to manufacture, especially at frequencies such as terahertz, infrared, and visible areas. Finally, and most importantly, it is difficult to increase the absorption capacity [28-34].

This study introduces a dual-beam absorber within a microwave frequency band.

In many designs, a three-layer structure is adopted, with two metal layers separated from each other by electrical insulation. The shape and dimensions of the first metal layer are chosen according to the work requirements. The last metal layer is often in the form of a flat surface that prevents any transmission of the electromagnetic wave and reflects waves like a mirror at the same time. The design consists of a metal ring placed on an insulating layer separating it from the copper ground layer. The results showed the presence of two distinct absorption regions that reach a peak of more than 99%.

The absorption mechanism of the dual absorbent consists of the interference of two different resonant frequencies. Additionally, the dimensions and design characteristics are controllable to expand the number of absorption zones to three or more.

Design:

In this paper, an absorbent is designed as a copper of X-shaped resonator separated from the ground layer by a type of insulation FR-4 with a thickness (h=1mm). The value of the relative permittivity 3.4.

Figure(1) displays the vertical projection of one cell of the proposed design on which the details of the dimensions are fixed as shown in Table (1). It should be noted that the metal used is copper with a conductivity of 5.8 x 107 s / m.

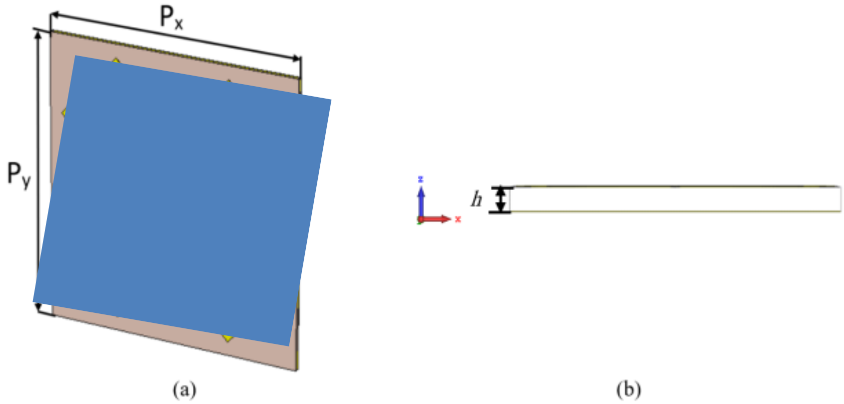

FIGURE 1.(a) perspective view showing the dimensions of one cell, (b) a side view.

TABLE 1. Dimensions details for the proposed design

Parameter	Value (mm)
Px	20
Py	20
h	1
L	24
w	8
g	1

The design was analyzed using (CST Microwave studio MWS) program in the frequency band from 8 GHz to 12 GHz, assuming that the waveform is of the basic type TE10. The wave propagation vector k is along the direction of the z-axis, and the electric field vector E is parallel to the direction of the y axis, the magnetic field vector H is parallel to the x-axis, and the type of analysis used is (Frequency domain analyzing).

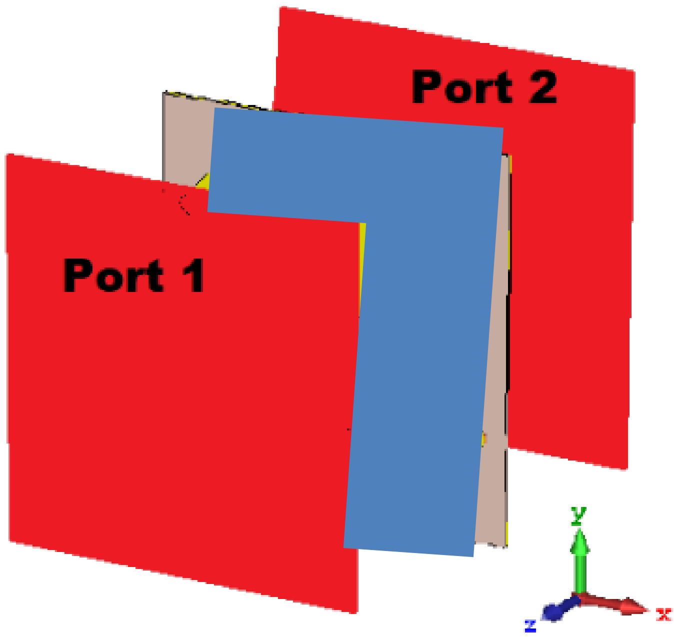

FIGURE 2.CST program settings.

Results

After extracting the S values using the CST program, the absorption values for the frequency are calculated according to the equation:

$$A = 1 - R - T \ (1)$$

Where the value of A represents the absorption coefficient, R represents the reflection coefficient, and T represents the permeability coefficient [22-25].

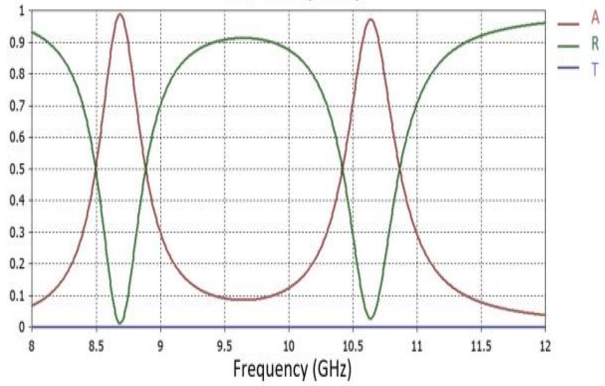

FIGURE 3. shows the spectrum of absorption, reflection, and transmission of electromagnetic radiation.

The design provides two absorption bands; The first is at a frequency of 8.65 GHz and with an absorption rate of 99.85%, and the second absorption area at a frequency of 10.60 GHz and the absorption rate of 99% as in Figure (3), presents the simulated results for the incident wave under normal incidence. Importantly, the incident wave is reflected with the unity magnitude R at two frequencies 8.65 GHz and 10.6 GHz, respectively. The absorption is equal to perfect at these frequencies.

For further clarification, the effect of the thickness change of the substrate FR-4 on the absorption level (Figure 4) was studied. The results showed that the increase in the insulating substrate thickness leads to a nonlinear increase in the absorption level. The results gave the highest value of absorption with h = 1 mm) thickness of the substrate. We also note that the resonant frequency decreases by increasing the dielectric substrate thickness, and also, we notice an increase in the frequency bandwidth. The results of the absorption is change by increasing the thickness of the substrate due to the higher substrate has to be compensated by increasing the loss component of the substrate.

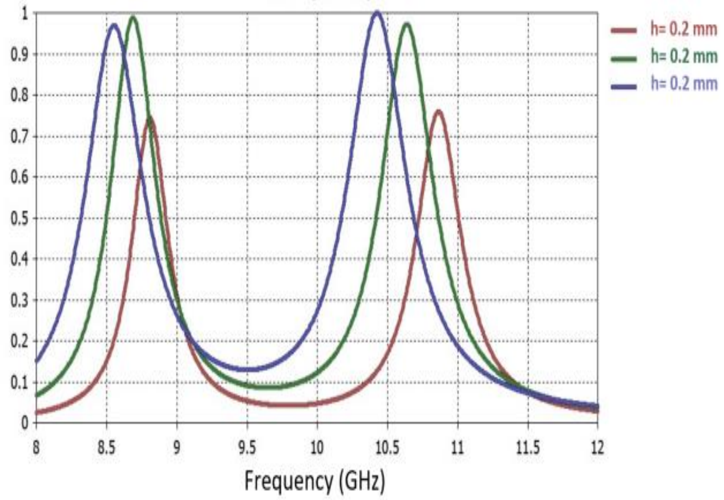

FIGURE 4. The effect of change in the substrate thickness on absorption level.

Negligible electric polarization effects are found in the change of azimuth angle, and therefore the change in phi angle cannot regulate the resonance frequency of this mode.

However, the variation of the phi could not change the absorption intensity therefore we can say this design electromagnetic polarization insensitive as shown in Figure (5).

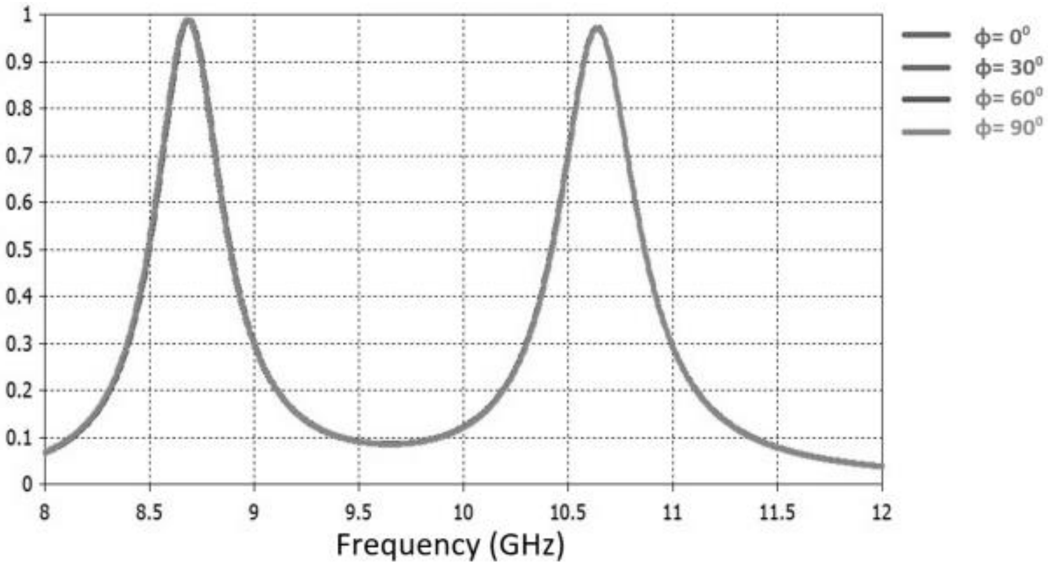

FIGURE 5. The effect of the change in the electrical polarization angle on the absorption level.

The results in Figure 5. shows that the absorption spectra does not change at different TE polarization angles, this due to the axisymmetric structure of the resonance unit cell. This indicates that the proposed metamaterial absorber is insensitive to TE polarization. This characteristic is very important in practical applications.

Figure 6 shows the simulated absorption, when the proposed design adopted the gap value of g = 0.5 mm, 1 mm, 1.5 mm and 2 mm. By adopting g, the absorption was improved obviously shifted from left to right for first peak. While second peak nonlinear change. Hence, by selecting a proper value for g = 1 mm, the proposed design obtained the good absorption results. The results of the absorption capacity and resonance frequency is change by increasing the gap between structure parts due to the higher electric coupling between metallic parts.

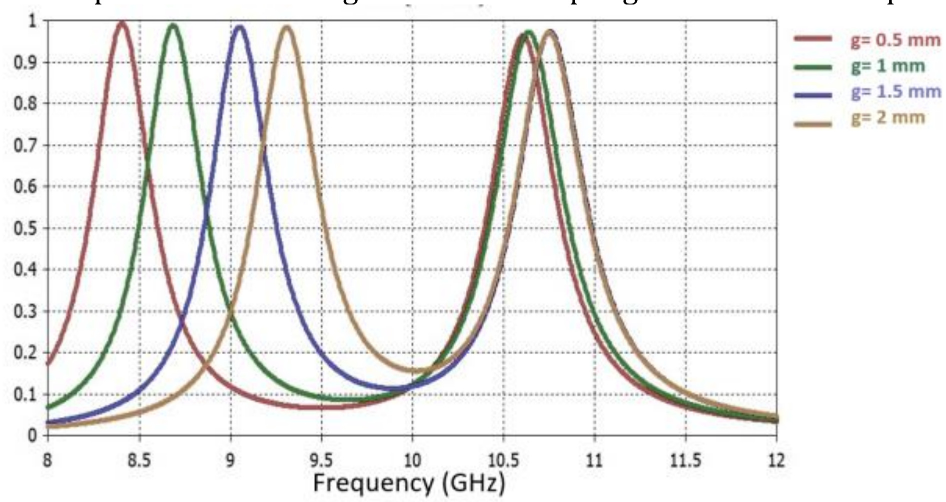

FIGURE 6. The effect of a change in the gap g on the absorption level.

Conclusion

The simulation results showed the possibility of producing an electromagnetic absorber with two perfect absorption bands as an X-shaped structure with its simplicity of design and thinness. This design can be used in many scientific applications such as weather satellites, solar cells and reduce the effects of electromagnetic waves. However, the results of controlling the geometric dimensions of the design showed the possibility of obtaining more control over the absorption levels and the absorption frequency. The results showed the highest value of absorption with h = 1 mm) and the proposed design obtained good absorption results by selecting a proper value for g = 1 mm. It is also worth noting that the design can be modified to operate at a variety of frequencies, including microwaves, terahertz, and optical.frequencies.

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