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MULTI-ELEMENT UNIT CELL METAMATERIAL ABSORBER FOR THE GHz FREQUENCY APPLICATIONS

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Abstract. In this paper, we used Computational Simulation Technology CST (2017) software to design and identify a perfect absorber material for metamaterial type (MMA), aiming for optimal absorption of electromagnetic waves in the GHz frequency band. By changing the size parameters of the constituent materials onto MMA, we achieved optimum structure with good absorption in the frequency range of 23.1 to 25.2 GHz and an absolute in the narrow band from 23.3 to 23.7 GHz. These findings are of significant importance in finding novel structural characteristics of MMA materials that exhibit complete absorption of electromagnetic waves within the K band frequency range (18-27 GHz). The optimal material after the investigation has great potential applications in absorbing electromagnetic waves, especially in devices such as military and aerospace radars, and in satellite communication systems that operate within the 18 to 80 GHz frequency region.

Keywords: CST MWS, metamaterial, absorber, GHz.

1. Introduction

Metamaterial absorbers (MMAs) are artificial materials composed of resonant circuits, possessing unique properties not found in natural materials. MMAs represent a category of metamaterial, originally proposed by Veselago in 1968 and further developed by Landy group [1, 2], but these artificial materials were not successfully fabricated until the early years of the 21st century, yielding interesting results and demonstrating high potential applications such as energy harvesting surface, electromagnetic wave stealth technology, super-lens, energy absolute absorption [3-6].

Since their inception, MMAs have attracted extensive research interest from materials scientists worldwide, including the scientific community in Vietnam. Several prominent domestic research groups have emerged, resulting in prestigious international

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publications with high impact [3-8]. However, the properties of this material are determined by the size parameters, material composition, and the arrangement of the base cells that make up the MMA. There have been many studies on MMA through (i) the arrangement of the base cells on the surface [9] or (ii) modification to the material composition of the MMA [10,11]. These methods are complicated, particularly the method of arranging the basic cells (i) due to the large number of material samples generated, posing challenges in achieving structure optimization.

In this paper, we investigate a new type of unit cell (UC), that employs four elements per UC. This UC thus functions as a "super-cell" and the dimension can be varied for better optimization. The absorbance of MMA is investigated by changing dimensional parameters. We show a simple method to generate the optimal structure compared to changing the material composition and arranging the unit cells in the full-size surface. Note that in the conventional method, the optimal structure was created by manually selecting UC types, making it difficult to find the best optimal structure, especially for structures consisting of many UCs. After investigating the absorbance of the sample through CST in the frequency range from 20 to 26 GHz, the results of the sample are quite good. Especially in this study, for the 23.1 to 25.2 GHz region, which falls within the operating frequencies of radar and aerospace, as well as some satellite communication systems, the absorption rate of the sample is almost absolute. In this report, we focus only on the simulations due to our limitation in measurement equipment shortly we will present the experimental result of this study.

2. Content

2.1. Results and discussion

In this paper, we have studied first the absorbance by changing the structural parameters of MMA with a 3-layer structure (Figure 1), including the first layer (copper layer) which is the top surface, made by copper plates with a thickness s = 0.03mm and conductivity $\sigma = 5.8 \times 10^7 Sm^{-1}$; the second layer (dielectric layer FR4) is the middle layer with a thickness of d = 1.6 mm; the third layer (bottom layer) is a flat copper layer with a thickness of s = 0.03mm. The initial optimized parameters are a = 20 mm; b =10 mm; e =1.6 mm; r = 0.8 mm; q = 1.2 mm, in which a is the dimension of a super basic unit cell. For the sake of simplicity, we fixed the value of a = 20 mm for the main unit cell in this research.

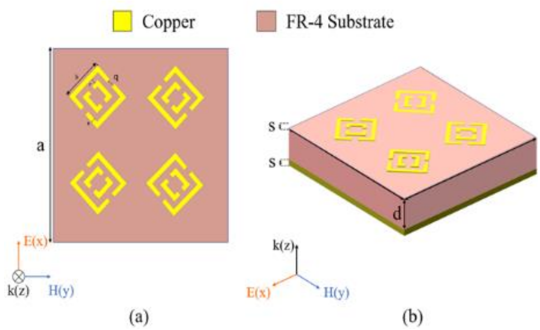

Figure 1. A unit cell of the structure of MMA in the study

To find the optimal structure with optimal dimensions, during the simulation, we proceed to change each parameter b, e, and r in turn and keep the remaining parameters unchanged.

First, we surveyed by changing the parameter b in the range from 10 mm to 11.2 mm, with a step size of 0.2 mm. We specifically chose to modify the b parameter as it is the main parameter of the unit element within the four-group element of the unit cell. Therefore, this study consists of a total of 7 simulations. Through our analysis, we determine that b = 10.8 mm is the optimal value for the reflection rate. The resulting reflectance spectrum of the sample is represented in Figure 2.

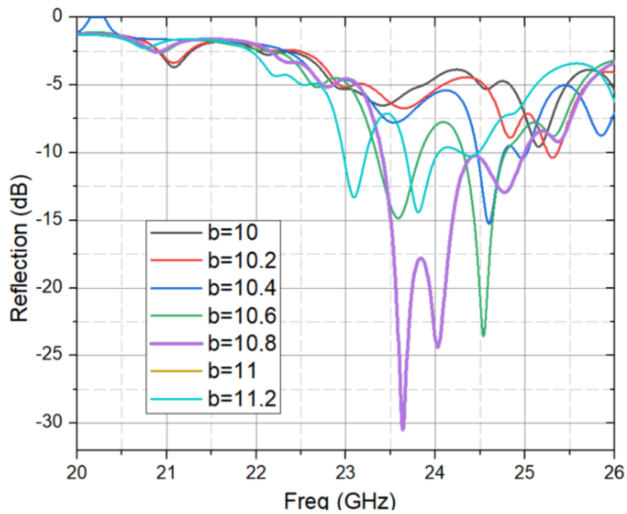

Figure 2. The reflectance spectrum of structure when varying parameter b

Next, we set b = 10.8 mm and proceed to change the values of the parameter e from 1.6 mm to 1.71 mm with an incremental step of 0.01 mm. We find that the optimal value of e is e = 1.7 mm. The reflectance spectrum with e = 1.7 mm is shown in Figure 3. This result shows that the reflection coefficient is diminished below -25 dB, which confirms a strong absorption rate of the structure in this frequency range.

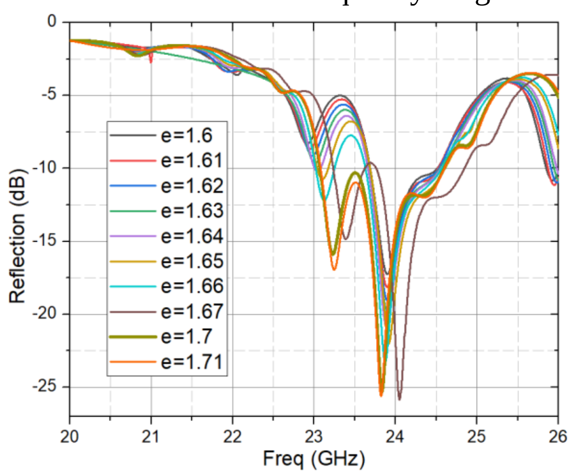

Figure 3. The reflectance spectrum of structure when varying parameters e

In the next step, we retain the e above and change the r from 0.75 mm to 0.91 mm with a step of 0.01 mm. We receive the results in Figure 4 below. We find that r = 0.9 mm gives the best reflectance in the frequency range from 23 to 25 GHz. Therefore, we adjusted r to r = 0.9 mm for the next calculations.

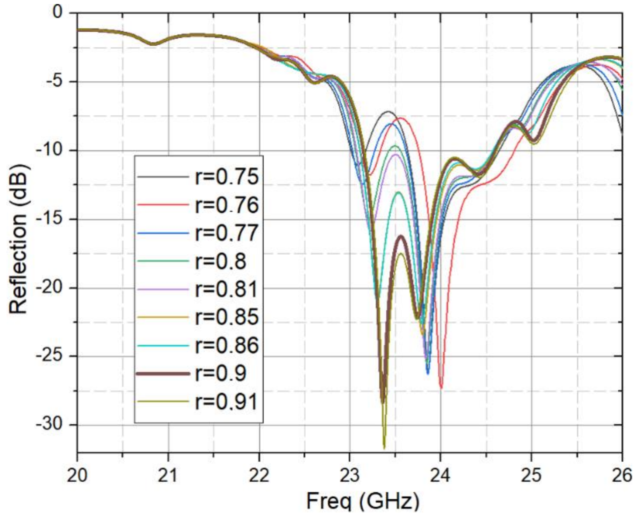

Figure 4: Reflectance spectrum by changing the parameter r

We finally found that the optimal absorption structure is the one with b = 10.8 mm, e = 1.7 mm, and r = 0.9 mm. Through CST, we obtained the best reflectance (Figure 5a) and absorbance spectrums (Figure 5b). Note that in Figure 5b the absorption is deduced from A = 1 – R, where R is the reflection (T is the transmission and T = 0 due to the copper back layer). Based on the obtained results, we can see that the absorbance is over 90% in the frequency region from 23.1 to 25.3 GHz. There are two peaks with a 100% absorption rate at 23.3 GHz and 23.7 GHz. This absorption band of the structure with the finalized dimension a = 20 mm in Figure 5 is the optimization case with the perfect absorption band over 95 % from 23.5 – 24 GHz.

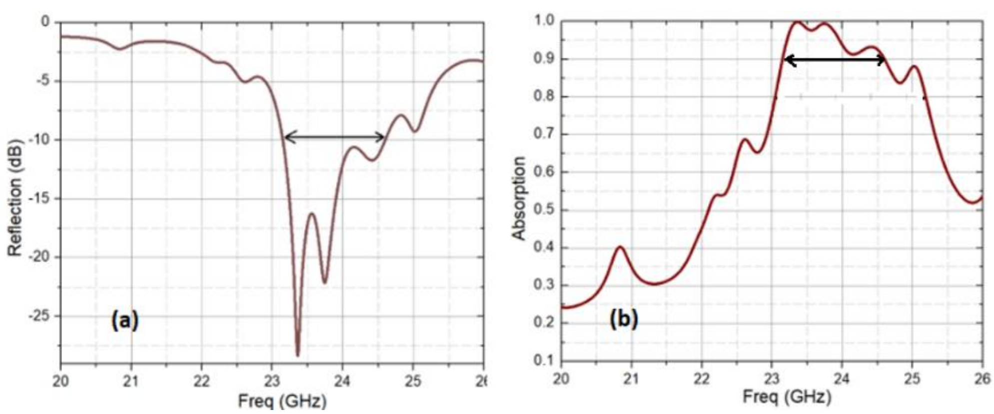

Figure 5. (a) The reflectance spectrum; (b) The absorption spectrum of the optimized structure

To better understand the absorption mechanisms of the structure, we conducted observations of the surface magnetic field and surface electric field of the structure in the absorption frequency range. The electric field density of the structure is observed through simulation, as shown in Figure 6.

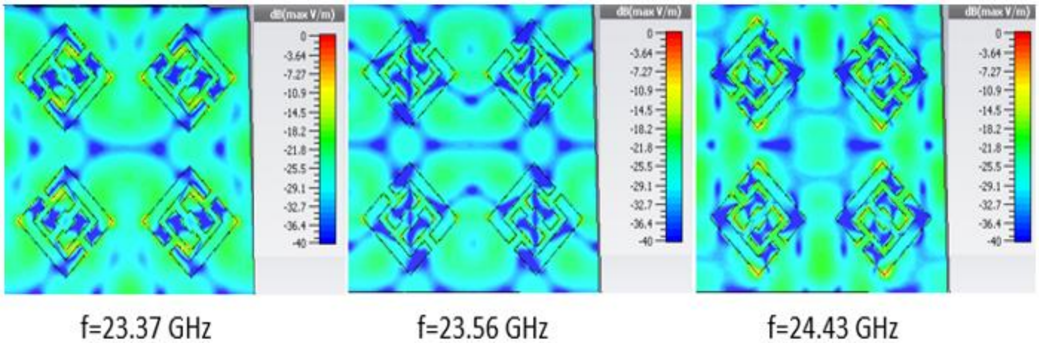

Figure 6. Electric field distribution density on the surface of the optimized structure

From the results, we can see that the electric field density at the highest peak frequency of 23.37 GHz is generally stronger on the surface of the material, where the electric field is concentrated in the unit cell element of the surface and on a discrete distribution on the surface of the top metal layer. At the other strong absorption frequencies of 23.56 GHz and 23.43 GHz, the electric field density is concentrated majority at the junction between the metallic patches of the unit cell and the junction between the unit cells. We also observe the electric field density at the other frequencies which are out of the working range (not shown), the surface electric field density is very weak and almost equals zero for these cases. This concentration confirms the strong absorption of the working frequency peaks. This also shows that by using multi-unit cells, we can use the strong coupling between the elements in the main cell to enhance the capability of the total absorber.

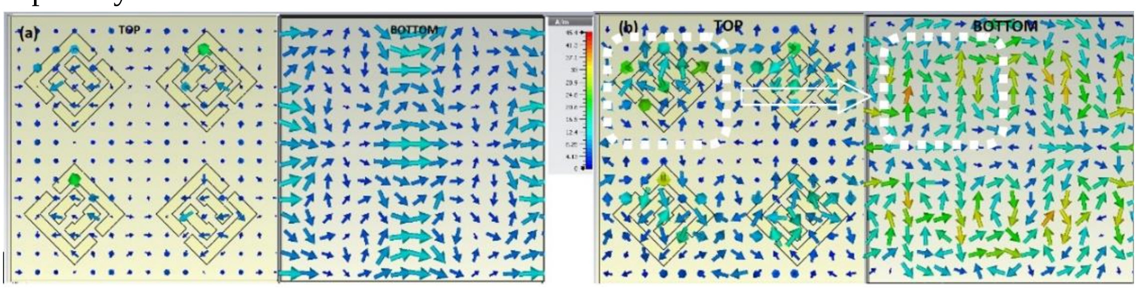

Figure 7. The surface currents of the structure at (a) 21 GHz and (b) 23.7 GHz

To further elucidate the structure's electromagnetic absorption mechanism, we observe surface current densities above and below the structure at two frequencies which are inside (23.7 GHz) and outside (21 GHz) of the perfect absorption band respectively (Figure 7). At a frequency of 21 GHz with weak absorptivity, we observe weak currents formed on the surface of the structure. In contrast, at a frequency of 23.7 GHz where the absorption is high at 95%, antiparallel currents are formed at the front and back of the structure, especially at the 4 positions of the unit element as illustrated in Figure 7b. These currents give rise to magnetic resonance and distribute the impedance matching of the surface with the environment, which results in the strong absorption properties of the structure at that frequency. The absorption mechanism at other frequencies in the band can also be explained in a similar way as above.

Polarization independence is an important material's performance in certain applications in specific situations [11,12]. For example, it is necessary for military radar when good absorption at different angles is required, for harvesting devices that take advantage of energy from all directions. Therefore, increasing the absorption capacity at a wide incident angle is an important requirement for the structure. In our study, the material has a well-fitting double symmetry, giving the expectation of maintaining high absorptivity at the maximum incidence angle. To study this aspect, we change the incident wave source with the same intensity at every possible large angle of incidence. The results obtained are as follows: it is clear that in the absorption frequency band, the intensity and the absorption frequency range of the structure are maintained when the incident angle θ changes from 0 to 45 degrees within the working range (Figure 8). This is highly interesting and effective for applications with a broad incident angle.

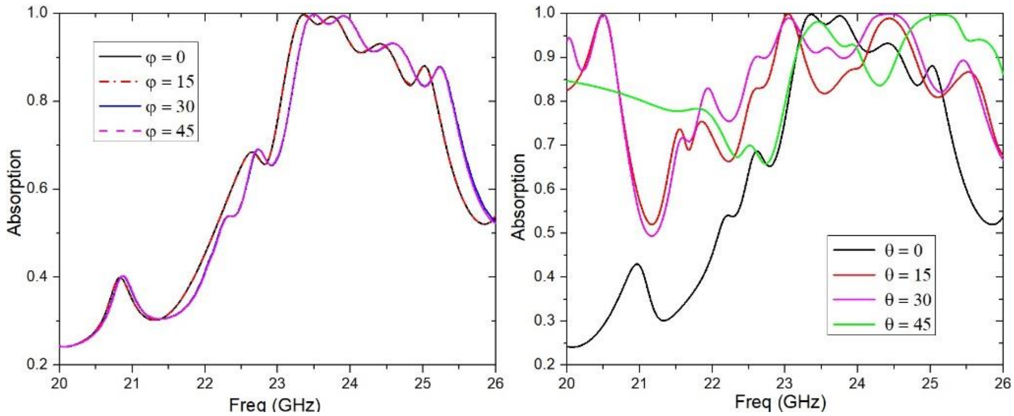

Figure 8. The dependence of the absorption to the φ and θ polarization angles

To verify the polarization conversion ratio (PCR) of the structure, we use the reflection coefficient S11 from the simulation to calculate this parameter following the method in [6]. The result is shown in Figure 9. We can see that, in almost the entire frequency range, the PCR is below 0.02 and maintained at a very small value. Therefore, this configuration can be considered not to affect the polarization conversion of the incident wave.

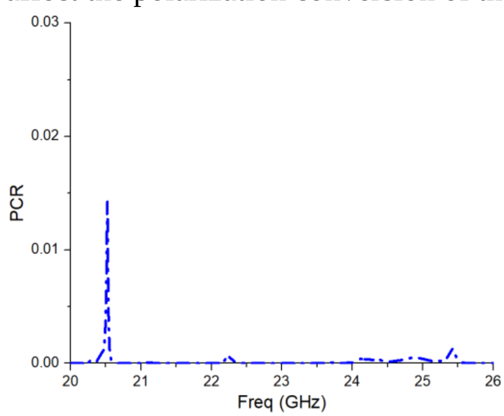

Figure 9. The PCR of the structure.

3. Conclusions

In this study, we investigated the absorbance of MMA supercell structures designed from three layers in the frequency region from 20 to 26 GHz by changing the size parameters of the components on the material to find the optimal case. Through the investigation, the absorbance of the structure depends greatly on the change of the dimensional parameters, which is completely consistent with the theory of MMA. Our optimized configuration has a good absorption band of over 95% in the working frequency range from 23.3 GHz to 23.7 GHz. Moreover, this structure is independent of polarization, which adapts well to multi-wave applications. This configuration can have many applications in the radar field, especially in military or satellite communications. However, the limitation in the measurement needs to be overcome in the next investigation of this structure in our research.

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