International Journal of MC Square Scientific Research Vol.15, No.2 2023

For use in C, X, and Ku band applications, a design of a super compact ultrathin perfect angle polarization independent metamaterial absorber was developed.

R. Praveena 1, S. Ramanikanth 2, V. S. Karthick 2, R. S. Tharun 2
Associate Professor 1, UG Student 2
Department of Electronics and Communication Engineering
Muthayammal Engineering College – Rasipuram, Namakkal (D.t), Tamil Nadu - INDIA

Abstract - An ultrathin, triple-band met material absorber that is exceedingly compact, polarization insensitive, and has wide angular stability is the subject of this publication's abstract. This absorber was developed by the authors of this research. Because the unit cell consisting of patches achieves virtually perfect absorption (approaching 100%), the term "perfect met material absorber" is appropriate to use in this context. At 4.75 GHz (C band), the building has an absorption efficiency of 99.96%, while at 9.47 GHz (X band) it is 99.98%, and at 14.40 GHz (Ku band), it is 99.62%. The volume of the building is only 7.20.80 mm3, despite the fact that its dimensions are relatively little. The thickness of the unit cell is 0.012 at its thinnest point when it is at its lowest cut-off frequency. A ring is located on the absorber's exterior, a split ring is located in the center, another ring is located on the absorber's interior, and there is a square line with triangular patches located on the sides. The electric or magnetic polarization of the incoming wave has no effect on absorption since it is matched and is not sensitive to it. In order to ensure that the suggested design is stable, a variety of incidence angles (for both TE and TM modes) and polarization angle combinations are tested. The values of absorption are found to be pretty close to 1. During the last step of the validation process, it was found that the simulated results and the measured ones were very well aligned.

Keywords - Absorber, Polarization insensitive, Triple-band, Wide-angle.

1. Introduction

Because there is extremely low transmission and reflection, devices manufactured from met material may be able to efficiently absorb electromagnetic (EM) radiation. Met materials are man-made structures that, when electromagnetic waves are passed through them, have a negative value of either permittivity or permeability or both of these properties. Because of this, the value of the refractive index decreases until it reaches a negative. There are a multitude of additional configurations of met materials that are recommended for application in a variety of scenarios. These configurations include single negative (SNG) and double negative (DNG). In spite of this, there have only been a few designs proposed using NZI or ZRIM met materials thus far. Increasing the gain, directivity, and radiation efficiency of antennas in the microwave, infrared, and visible light spectral ranges; performing super-reflection and cloaking; measuring the refractive index of objects; and attenuating coaxial signals are some of the most important real-world applications of NZI met materials.

The value of the refractive index is also equal to zero when the ratio of permittivity to permeability is equal to zero. It is possible to increase antenna gain by using NZI and ZRIM metastructures because these materials prevent electromagnetic waves from entirely reflecting off their surfaces. According to Snell's law, the wave that is refracted from the medium into air will have a direction that is normal to the interface if the effective refractive index of the medium is zero or near to zero. This is the case when the effective refractive index of the medium is zero. This NZI or ZRIM property comes in beneficial in situations when incoming electromagnetic waves need to be accurately absorbed or transmitted through it, such as in electromagnetic cloaking or stealth technologies. If NZI meta-structures are utilized in high-frequency antenna or antenna array systems, they may boost the directivity of the antenna radiation. This is because the near-zero value of the refractive index may result in the perfect transmission of the incoming electromagnetic waves in a particular direction. In order to provide reliable transmission, high-frequency antenna systems need careful control of their directivity.

When applied across the NZRIM surface, any medium with the necessary refractive index, which is often negative, is able to be recognized and detected, which makes the NZRIM structure excellent for refractive index sensing in microwave communication-based sensing systems. Additionally, NZIM structures may have use in super-reflection and cloaking technologies. As a result of these considerations, research was carried out to design blueprints for the NZIM and ZRIM buildings.

Because the majority of near-zero or perfect zero-refractive index MM or MM absorbers that have been manufactured to this day have not exhibited cross-polarization analysis, these materials do not qualify as ideal met material. Because of the inclusion of lumped elements and substrate-embedded transmission lines in their respective designs, these near-zero MM absorbers are notoriously difficult to construct. Although some near-zero absorbers have shown wide band near-zero refraction, none of them have been able to produce precise zero refraction, much alone near-zero refraction, throughout the whole operating frequency range. This is despite the fact that some near-zero absorbers have shown broad band near-zero refraction. It is claimed that near-zero refractive met materials may be used in infrared, microwave, and THz applications, in addition to a range of patch designs and substrates. Only a limited few NZIM and ZRIM absorbers are acceptable for use in microwaves, despite the fact that there are a number of these types of absorbers available for use in the photonic and optical frequency regimes.

In this research, we describe a multilayer NZIM absorber that may be used on a single substrate and is intended for use in microwave applications, specifically to increase antenna gain and directivity. The proposed NZIM absorber was created by making use of a conventional FR4 substrate (with a thickness of 1.6 millimeters and a dielectric constant of 4.3) in conjunction with a straightforward patch layout. When the dimensions of the patch are maintained to a bare minimum, the absorber array's periodicity may be increased to its full potential. This design does not include any components that are lumped together or implanted into the substrate.

1.1 Existing Method

The bandwidth and absorption rate were increased primarily via the use of these three technologies. The first method entails forming a large unit cell out of a number of smaller subunits to be used in the construction. The next thing that has to be done is to make a new kind of unit cell by combining a few different metal-dielectric layers in a vertical stack. The foundation of the third and final possibility is a cascaded cavity design that makes use of doped grapheme, silicon, or other composite materials.

1.2 Proposed Method

Studies conducted in the past have shown that the huge unit size of multi-band GHz met material absorbers (MMA) is caused by the presence of stacked layers as well as many resonators contained inside a single unit cell. It is because of this that putting it into practice becomes challenging. As part of this project, we are going to develop a unique multimode antenna (MMA) that has a broad frequency range and does not depend on stacked layers or a large number of resonators.

2. Literature Review

In the year 2020, Annou et al. [1] proposed the existence of a novel double-negative metamaterial in the form of a bowtie. The proposed design for the met material was put to the test using two different substrate materials—FR-4 and Roger RT 6010—and the results were compared between the two. In addition, 1 2, 2 2, and 3 3 array cell studies were carried out throughout the course of this research. Metamaterial with the shape of an upside-down horizontal L, designed specifically for use with microwaves. A square split-ring resonator is located on the outside of the L-shaped structure that makes up the suggested design for the metamaterial.

Two different shaped metamaterial designs were presented by Tayaallen et al. [2] for use in C-band and Ku-band applications in the years 2019 and 2020, respectively. The authors of the initial research effort presented a compact-sized circular split-ring resonator that was designed specifically for the purpose described. In the meanwhile, the second line of research concentrated on improving the performance of metamaterial design structures by combining circular and square-shaped components. These research were effective in revealing singular left-handed traits for each separate study, most likely at the Ku-band and C-band frequencies, respectively.

In 2015, Samasuzzaman [3] made a proposal for a circularly polarized patch antenna that might be used for satellite communication systems. This inquiry made use of CST software that was based on the finite integration technique and was available for commercial purchase. During this time, the HFSS was modified to accommodate the validation of the simulation findings. On a dielectric substrate material composed of FR-4, the authors developed and constructed the suggested metamaterial.

Jubaer et al. [4] conducted research on a metamaterial-based bandpass filter with an Aztec-shaped configuration for use in triple-band microwave applications. An examination of a small number of array cells, such as 2 by 1 and 2 by 2, was subjected to a comparison study. This research made use of the FR-4 substrate material in order to evaluate the performance of vBesides satellite applications, the absorber field used metamaterial design in order to demonstrate better results after the breakthrough of remarkable features in the metamaterial.

2.1 System Function

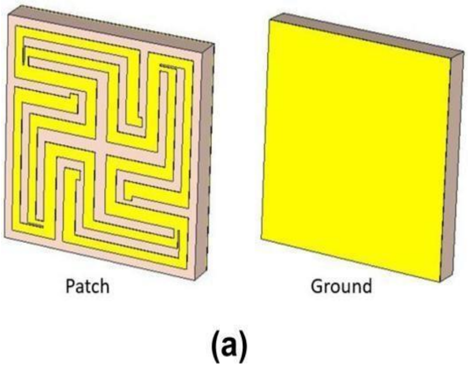

Fig.1 shows the patch and ground design of the unit cell

The design parameters that are shown in Fig. Consider a quadrant in order to grasp the meaning of clause 1(b). Due to the fact that the patch has a four-fold rotational symmetric structure, just one of the patch's quadrants was selected for explanation; this particular quadrant is denoted by a dotted redline enclosure in Figure. 1(b). As a result, the size of the complete patch may be determined by supposing this quadrant to be replicated at 90, 180, and 270 degrees of rotation at each of the other quadrants. A magnified picture with specific proportions is shown of the quadrant that was picked. Table 1 has an exhaustive listing of all of the patch's dimensions in minute detail. The size of the unit cell is 12 millimeters, which guarantees the smallest possible unit cell size (0.16952 or /6) in accordance with the /4 criterion at the lowest resonance frequency (4.238 gigahertz).

On the CST, a simulation was run taking the FSS unit cell into consideration using a phase reflection diagram and a frequency domain solver. This was done for each and every potential incidence angle of co-polarized waves. It was decided that the electric field would be ideal along the x-axis, the magnetic field would be perfect along the y-axis, and the electromagnetic wave would move along the z-axis. In order to achieve the desired excitation mode, the tetrahedral mesh of the structure was used. In addition, floquet ports were selected for the unit cell in order to perform cross-polarization analysis by taking into account the boundary conditions of the unit cell along the x- and y-axes. In order to compute all of the parametric findings, S parameters were extracted.

PERFORMANCE ANALYSIS OF THE ABSORBER

2.1 An examination of co-polarized electromagnetic waves

Figure displays the distributions of the surface current as well as the electric field at each of the resonance frequencies. 3. At the resonance frequencies, it is possible to see that the patch has been energized in a manner that is pretty comparable. It is anticipated that the excited fractional regions beneath the patch are being agitated at the plasma frequency, which tends to be similar to the applied electromagnetic frequency. As a consequence of this, the unit cell experiences the least value of permittivity, permeability, and a value close to zero for the refractive index , while also experiencing the highest absorption at the resonance frequencies.

Absorption of the incident wave by the unit cell when it is co-polar

The simulation was run for initial arrays of 1 x 3 and 2 x 2 sets of adjacent unit cells with the purpose of demonstrating that there is no mutual interaction between neighboring unit cells in a full absorber. The levels of absorption achieved by these principal arrays are shown in Figure 1. 5, Fig. 6. The arrays have showed identical findings whether seen at normal and oblique incidences, with the exception of a little divergence from the resonant frequencies at 450 phi (for the 1 x 3 array) and 300 theta (for the 2 x 2 array). In Fig. At position 6, a noticeable shift can be seen in the absorption peaks with a theta polarization of 30 degrees. This occurred as a result of the shifting of resonance frequencies for cumulative inductive sections among the unit cells, as well as the addition of capacitive gaps at any two sides (of four sides) of each unit cell. This was the cause of the phenomenon. Nevertheless, as can be shown in Fig. 5. Because of the same reason, the largest resonance peak is absent at 90 degrees theta and 45 degrees phi. This issue is resolved in the event where the array in question is full, has a limited number of unit cells, and all of the unit cells are surrounded by four unit cells that are identical to themselves.

Analysis of the structure of metamaterial arrays

The gathering of data for a number of arrays of met material cells, such as 1 x 2 (8 x 16 mm2), 2 x 2 (16 x 16 mm2), 2 x 3 (16 x 24 mm2), and 3 x 3 (24 x 24 mm2), was carried out. If you want to use merely a unit cell structure for your practical application, you won't be able to get the superior electromagnetic characteristics you're looking for. Consequently, the array cell structures were numerically simulated with the use of CST software by using a modeling procedure that was similar to the one used with the met material unit cell. In this simulation, the unit cell was placed according to the number of rows and columns that were chosen (the unit cell dimension is described in Section 2.5). No adjustments were made to the unit cell. Fig. 4 depicts the S11 and S21 findings obtained from each of the different array cells. Results of the reflection and transmission coefficient measurements were shown for each of the four distinct met material arrays. Dual-band resonance frequencies may be seen in the met material array structures, namely in the X-band and the Ku-band. The findings that were presented, which showed that increasing the number of rows and columns did not seem to change the scattering parameters, allow for a straightforward conclusion to be drawn. The fact that the differences between each array cell were insignificant, amounting to less than 0.01%, made the procedure of selecting the arrays the least difficult one possible. Because of the size restriction, we decided to go with the most compact array cell shape possible for the application in question. As a result, the 1 x 2 array cell that had 0.12% more dissimilarities to the CM unit cell was chosen for selection. In addition to this, the array structure that was presented is not inconsequential for the application of the communication system, and it is also easier to apply.

3. CONCLUSION

It has been suggested that C, X, and Ku band antennas, in addition to other uses, might benefit from a perfect met material absorber. The design of the patch was simple, and there were no parts that were lumped or incorporated into the substrate. According to the requirements, the size of the unit cell is 0.169 microns, which places it in the lowest possible dimension range. From the modeling all the way up to the measurement phase, the proposed NZIM absorber has shown flawless (and near-unity) absorptions at 4.238 GHz, 7.836 GHz, and 13.5 GHz.10.482 GHz, 11. 014 GHz and 13.352 GHz. This absorber is now flawless because to the cross-polarization study that was done on it. Furthermore, it has a near-zero refractive index property at resonance frequencies, as well as a near-zero refractive index throughout its entire operating frequency range. This makes it a perfect NZIM absorber, which is not available in any recent relevant works. Due to this NZIM absorber's one-of-a-kind property, it is suitable for use in antenna systems in order to improve gain and directivity. Additionally, the NZIM absorber may be used for additional applications, such as measuring the refractive index of a medium or concealing electromagnetic radiation at the C, X, or Ku bands.

References

1. Kaur KP, Upadhyaya T. Wide-angle and polarisation-independent tri-band dual-layer microwave metamaterial absorber. IET Microwave Antenna Propog. 2018;12(8):1428-1434.
2. Zamzam P, Rezaei P, Khatami SA. Quad-band polarizationinsensitive metamaterial perfect absorber based on bilayer graphene metasurface. Phys E. 2021;128:1-8.
3. Bhattacharya A, Bhattacharyya S, Ghosh S, Chaurasiya D,Srivastava KV. An ultra-thin penta-band polarization-insensitive compact metamaterial absorber for airborne radar application.Microw Opt Technol Lett. 2015;57:2519-2524.
4. Munaga P, Bhattacharyya S, Ghosh S, Srivastava KV. An ultrathin compact polarization-independent hexa-band metamaterial absorber. Springer Appl Phys. 2018;24:331.
5. Kaur M, Singh HS. Design and analysis of a compact ultrathin polarization- and incident angle-independent triple band metamaterial absorber. Microw Opt Technol Lett. 2020;62(5):1920-1929.
6. Wanghuang T, Chen W, Huang Y, Wen G. Analysis of metamaterial absorber in normal and oblique incidence by using interference theory. AIP Adv. 2013;3:102118.
7. Sun J, Liu L, Dong G, Ji Z. An extremely broad band metamaterial absorber based on destructive interference. Opt Express. 2011;19:21155
8. Agarwal M, Behara AK, Meshram MK. Dual resonating C-band with enhanced bandwidth and broad X-band metamaterial absorber. J Appl Phys. 2016;166:1-9.
9. Li MH, Yang HL, Hou XW, Tian Y, Hou DY. Perfect metamaterial absorber with dual bands. Prog Electromag Res. 2010;108:37-49.
10. Li H, Yuan LH, Zhou B, Shen XP, Cheng Q, Cui TJ. Ultrathin multiband gigahertz metamaterial absorbers. J Appl Phys. 2011; 110:909-912.

11. Marathe D, Kulat K. A compact triple-band negative permittivity metamaterial for C, X-band applications. Hindawi Int J Antennas Propag. 2017;2017:7515264.
12. Pendry JB, Holden AJ, Robbins DJ, Stewart WJ. “Magnetism from conductors and enhanced nonlinear phenomena”. IEEE Transaction Microwave Theory Technol 1999;47 (11):2075–84.
13. Landy NI, Sajuyigbe S, Mock JJ, Smith DR, Padilla WJ. “Perfect metamaterial absorber”. Phys Rev Lett 2008;100(20):2074021–24, DOI: https://doi.org/10.1103/PhysRevLett.100.207402.
14. Ramya Sekar, Srinivasa Rao Inabathini, “An Ultra-thin Compact Wideband Metamaterial Absorber” Electromagnetics Radio Engineering, Vol. 27, NO. 2, June 2018, DOI: 10.13164/re.2018.0364
15. D. Sood, Chandra C. Tripathi, “A Compact Ultrathin Ultra-Wideband Metamaterial Microwave Absorber” Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 16, No. 2, June 2017
16. Xiangkun KONG, Junyi XU, Jin-jun MO and Shaobin LIU, “Broadband and conformal metamaterial absorber” Front. Optoelectronics. 2017, 10(2): 124–131 DOI 10.1007/s12200-017-0682-z
17. Thtreswar Beeharry, Riad Yahiaoui , Kamardine Selemani and Habiba Hafdallah Ouslimani, “A Co-Polarization Broadband Radar Absorber for RCS Reduction”, Materials 2018, 11, 1668; doi:10.3390/ma11091668
18. Quanlong Yang, Xieyu Chen, Yanfeng Li, Xueqian Zhang, Yuehong Xu, Zhen Tian, Chunmei Ouyang, Jianqiang Gu, Jiaguang Han, and Weili Zhang, “Aperiodic-metamaterial-based absorber” APL Materials 5, 096107 (2017)
19. Gobinda Sen, Sk. Nurul Islam, Amartya Banerjee, and Santanu Das, “Broadband Perfect Metamaterial Absorber on Thin Substrate for X-Band and Ku-Band Applications” Progress in Electromagnetics Research C, Vol. 73, 9–16, 2017 DOI: 10.2528/PIERC17011101
20. Tak J, Jin Y, Choi J. A dual-band metamaterial microwave absorber. Microw Opt Technol Lett. 2016;58:9
21. Huang L, Chen H. Multi-band and polarization insensitive metamaterial absorber. Prog Electromag Res. 2011;113:103-110
22. Dhillon AS, Mittal D, Bargota R. Triple band ultrathin polarization insensitive metamaterial absorber for defence explosive detection and airborne radar applications. Microw Opt Technol Lett. 2019;61(1):89-95
23. Kavitha Muthukrishnan & Venkateswaran Narasimhan, “An Ultra-Thin Triple-Band Polarization-Independent Wide-Angle Microwave Metamaterial Absorber” Plasmonics https://doi.org/10.1007/s11468-019-00985-y
24. Saptarshi Ghosh, Somak Bhattacharyya, Yadunath Kaiprath, and Kumar Vaibhav Srivastava, “Bandwidthenhanced polarization-insensitive microwave metamaterial absorber and its equivalent circuit model”, Journal of Applied Physics 115, 104503 (2014)
25. Peng Zhou, Gaige Zheng, Fenglin Xian, Linhua Xu, “Dynamically switchable polarization-independent and broadband metasurface perfect absorber in the visible and near-infrared spectra regime” Results in Physics 11 (2018)