A Review on Metamaterial Absorber based on Fractal geometry

Wassan Hassan Yaseen 1* Ghufran M. Hatem 1* Abdulkadhum J.Yasiri1*
1Department of communication engineering Najaf Technical College, Al-Furat Al-Awsat Technical University (ATU) , Al-Najaf Al-Ashraf, Iraq
Email: Wassan.Yaseen.Me.etch @ student.atu.edu.iq

Abstract—

Defense modern communication systems have recently required more complicated design and operating features. Smaller devices can be combined for different communication systems and implemented in one user's device board. Furthermore, the cost of structure production should be kept to a minimum. The absorber of these devices should be compact, light, operate in various frequency bands, and/or be broadband to meet part of that request. There are numerous research strategies for achieving this goal, one of which is the use of fractal geometries for absorber element shape. Many fractal forms have been proposed for such applications in recent years, and the constructed antennas have greatly improved. In addition of using fractal the use of Metamaterial (MMT) with negative permittivity and permeability values to design absorber and get a high absorption rate is recently investigated. The advantages of employing fractal-based MMT arrangement to create radio and microwave absorbers were discovered in this paper.

This paper provides a good review of the different fractal geometry types that are used to design MMT absorbers. This study's objective is to showcase the most recent discoveries and academic studies related to the subjects mentioned above.

Keywords:Metamaterial, fractal geometry, absorber, self-similarity, space filling.

DOINumber:10.14704/nq.2022.20.8.NQ44898 **NeuroQuantology 2022; 20(8): 8758-8764**

INTRODUCTION

Engineers and scientists working in this field have noted the rapid growth of communication technology over the years. People have been encouraged to best their life goodness by utilizing technological breakthroughs. In the electronics turf, microwave absorber is used to reduce the quantum of electromagnetic wave upset Electromagnetic interference (EMI) [1–2]. However, that once coated material is enveloped by microwave absorber, the impact of EMI can be avoided. This behavior is depicted in Figure 1. Defense (military) [3, 4]. As shown in Figure 2, this reflector is used to coat or spray military facilities and equipment such as “strike aircraft”, “warships “(war ships), and “military uniforms”, especially personnel in the guard front. A radar system's transmitter sends out microwave in all directions all the time. If this wave hits something, the signal is reflected and transmitted to the receiver. This relative contribution indicates the existence of a nearby item, that will be displayed during the radar scanner. Radar (radio detection and ranging) is a microwaves technique for detecting, measuring, and mapping things. Radar waves can detect the presence of targets [1]. The radar calculates the range between the target and the radar. The ranges measured by the time delay between the transmitted and reflected signalto the radar. The radar can reveal the presence of these objects because the target may reflect electromagnetic radiation. The radar, on the other hand, will be unable to detect the item if it does not reflect radar signals[2]. This tendency is then used for the benefit of a certain defensive system. Microwave absorbent materials are widely used, and it is well understood that they can lower the power of electromagnetic waves[3]. These microwave absorptive materials can be utilized outside or inside to reduce or eliminate reflections or transmissions from specified objects[4]. This microwave absorbent can also be utilized to create an environment that is devoid of reflections or anechoic.Many researchers have used a number of novel techniques to design a microwave absorber for many purposes[4].This study provides a brief introduction of metamaterial absorberfor microwave and optical applications This research examined the use of fractal geometry as an absorber elementfor MMT in the design of absorber in order toincrease absorption rate and give a wide bandwidth suitable for numerous radio, microwave and optical applications.

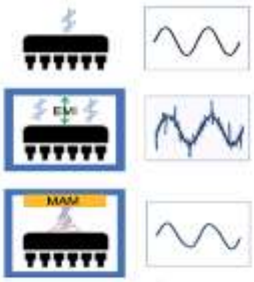

Figure 1: Microwave absorbers are used

Figure 2: Microwave absorbers in military applications [4]

METAMATERIAL ABSORBER

In the field of telecommunications, MMT absorbers are well-known, especially for antennae [5] and radars [6]. The electric field concentrates towards the waveguide boundary [5,6] because the index of refraction of a single bad MMT and the transverse propagation constants of a MMT microwave are both imaginary integers. A fundamental property of this type of MMT is the field's propensity to concentrate at the interface of a single negative MMT. It's a technique for making microwave absorbent materials. In most materials, a dielectric spacer sits between a MMT material and a metal plate layer. Unity absorptivity could be obtained by matching material's impedance to that of free space using this type of cutting-edge technology. In addition, good device design can lead to wide-angle, polarization-insensitive, and even multi-band/wide-band absorption [13-17].

Furthermore, previous MMT research has revealed that the absorber catches and converts the incoming electromagnetic (EM) wave to heat in specific locations of the devices [7, 12]. Because of their properties, MMTs are particularly useful in EM detectors and imagers, anti-electromagnetic interference, stealthy technology, phase imaging, spectroscopy, and thermally emission. Tunable devices, which enable real-time control and modification of electromagnetic waves, are a popular topic in the MMT field [18].

FRACTAL GEOMETRY

B.B. Mandelbrot, a French mathematician, created the term fractal when he released his seminal work "The Fractal Geometry of Nature" in 1970[19]. He showed that fractals exist in nature and that they may accurately describe some irregularly shaped entities or structures in nature that are not supported by Geometric shapes, such as trees or mountains, demonstrating that fractals work in non-integer dimensions. He invented the term fractal by expanding on the concept of a fractional dimension. A fractal, according to Mandelbrot, is a shattered geometric object that can be split into parts, each of which is (approximately) a smaller version of the whole that can be repeated indefinitely[20].

FRACTAL PROPERTIES

Self-similarity and non-integer dimension are two of the most crucial features of fractals. The same is true with fractals: you may magnify them several times and see the same shape each time. It is more difficult to explain the non-integer dimension Integer-dimensional objects such as 0-dimensional points, 1-dimensional lines and curves, 2-dimensional plane figures such as squares and circles, and 3-dimensional solids like as cubes and spheres are all dealt with in classical geometry. On the other hand, many natural occurrences are best described by a dimension of two whole integers. The size of a fractal curve depends on how much area it actually takes as it twists and curves. The more a plane is occupied, the closer a flat fractal comes to two dimensions[19].

The mathematical fractal geometry has been known for over a century, and it is based on iterative equations, which are a type of feedback based on recursion. The Sierpinski carpet (a), Sierpinski gasket (b), Koch curve (c), and the MSK curve (d) are examples of these mathematical structures (4). [19]. The application of fractal principles in the building of an antenna and absorber minimizes the antenna or absorber size without sacrificing performance. Self-similarity, space-filling, and fractal dimension are three common aspects of fractal geometries[20]. It has been demonstrated that the self-similarity property of fractal forms may be used to effectively create multiband fractal antennas, and that the space-filling ability of fractals can be used to minimize absorber size. The fractal dimension feature has long been used to distinguish fractal geometries from Euclidean geometries. [20]. Figure 3 shows some of Mathematical fractal geometry examples.

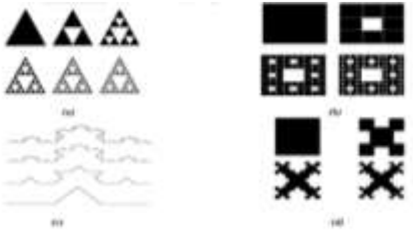

Figure (3): Mathematical fractal geometry examples, (a) Sierpinski Gasket, (b) Sierpinski Carpet, (c) Koch Curve, (d) MSK curve [19]

RESENT MMT BASED FRACTAL GEOMETY REVIEW

Metamaterial absorber by using fractal geometry is becoming an increasingly important design for military application to cover the areas of radar, microwave and optical applications. Based on their performance to enhance the most properties of these absorber, we classify this review according to the enhancement in their performance such as Bandwidth Enhancement, getting Wideband and multiband and Miniaturization.

A. Bandwidth Enhancement

The unit cell's X-band bandwidth is increased by using a fractal-based broadband polarization sensitive perfect MMT absorber [21]. The absorber's total width half maximum is 18.5%. The absorber in rotational symmetry structures is polarization insensitive, allowing for future applications including radar target stealth, antenna design, and electromagnetic interference [21].

For super-duper terahertz (THz) fractal based MMT absorber (MA), the higher metals patches, bottom metal reflector, and single dielectric substrates with them have been created [22]. MA was created by approaching the resonant frequency of each other, with an operating range of 6.39 to 9.47 THz and a relation width (RB) of 38.8 percent. Altering the ratio between the four sets of resonators may increase the absorption bandwidth, and adjusting the dielectric height can enhance the absorption spectrum's efficiency. When an electromagnetic wave penetrates, the processes of FP cavity resonance and surface plasmon polaron (SPP) resonance occur, causing incoming light energy to be absorbed, according to the research. They also ran simulations to see how different MA parameters affected absorption performance, and discovered that the height of the dielectric layer and the ratio between the four sets of resonators had a big impact on MA performance. The proposed absorber construction affects the incidence angle more than the polarization angle. It has a wide range of applications and excellent functionality [22].

In [23], the author shows how to make a metal E-shaped fractal-based perfect MMTabsorbers (PMA) with a broad absorptivity in the microwaves regime's K- and Ka-bands. On the upper surface of the PMA, square-shaped split-ring resonators surround the fractal design (SRRs). The absorptivity of PMA was tested for normal and oblique incident waves in the 20-30 GHz region. To test the suggested design's robustness, the longitudinal electric (TE) and magnetization (TM) modes were used Fractal resonators have a capacitive effect at low frequencies, but SRRs do at higher frequencies. The observed and simulated results were found to be almost identical. For normal incidence waves with TE- and TM-polarized excitations, the FMA achieves the highest absorptivity of ~80%. However, at particular operating frequencies, the structure shows near-perfect wave absorption. The suggested absorber spans the 5G frequency spectrum, making it beneficial for filtering, antenna isolation, and attenuation applications in future 5G communication systems.

B. Wideband and multiband properties

A tungsten-based ellipse rings-shaped fractal metasurface with an average absorption of more than 90% over the visible wavelength range of 400–750 nm [24]. The qualities of total absorption can be observed due to the localized surface plasmon resonance, which causes impedance matching. In optoelectronic applications, the absorber can provide up to 70% absorbance even with an incident obliquity of 0°–60° for transverse electric polarization. In order to maximize the results, the performance was evaluated using the figure of merit and operational bandwidth. The suggested absorber is appropriate for a variety of photonics applications, including photovoltaics, thermal emitters, and sensors, due to its significant absorption throughout the whole visible spectrum, Stability over a wide range of angles and the utilization of low-cost metal [24].

A tree-shaped microstructure made consisting of two dielectric substrates, a three-dimensional fractal metal tree, and four lumped resistances was used to build a perfect MMTabsorber that was ultra-wideband, polarization-insensitive, and had a high absorption rate [25]. This absorber had an absorptivity of more than 80% and a relative bandwidth of 86.9%. Wideband, wide-incident, and polarization-insensitive absorption properties The polarized-insensitivity and wide-incident absorption properties of the proposed MMTabsorber were studied using near electric fields, angular absorptions, and surface current distributions. As a result, at microwave frequencies, the broadband absorber can be used for stealth technologies and acoustic clocks.

By using geometrically symmetric fractal element properties to provide a variety of applications ranging from microwave to optical frequencies, so [26] proposed THz fractal HIS MMTwith absorption performance be increased further variations in incidence angle and polarization are particularly sensitive to typical MMT properties [26].

A wide-band MMTabsorber (MA) was proposed in [27] employing Minkowski fractal (MSKF) frequency selective surface and resistive layers. The absorption is polarization-insensitive and wide-angle, and the total thickness is only 0.8 mm. Because of the multiband resonance qualities of the Minkowski (MSK) resistive films' Ohmic loss capability and fractal loop structure, this composite MA has a numerically absorptive bandwidth of around (19) GHz in the range (6.51–25.42) GHz. This concept gives a practical and successful method of producing a beamy-band absorber in permeation technology. Two typical ways for creating resistor film layers include silk-screen printing resistant droplets into a pattern or putting a thin pattern resistive film over a dielectric material with a ground plane.. Controlling the square resistive layer thickness can change the surface resistance value. This design offers a practical way to widen the absorber's band [27].

In [28] proposes a UHF dual band fractal absorber based on a MMTstructure with a reduced dimension (<λ/2 on the both frequencies of operation) and a substrate thickness of only a few microns (≈ λ/100). The decreasing properties of the suggested fractal shape are used to produce a dual-band MMTabsorber cell. Extremely significant absorption peaks (> 99 percent) have been reproduced around the optimal operating frequencies (i.e.,"878 MHz" and "956 MHz"). showing the design's capacity to deliver the necessary absorbing condition under the double modality while preserving thickness and size in comparison to standard microwave absorption configurations.

They created a tunable wideband graphene-based ideal plasmon absorber in the near-infrared spectrum [29] by using square fractal geometry. A graphene sheet is sandwiched between two MgF_2 layers, with a fractal array of gold squares in between. A single layer of graphene was used in the intended absorber instead of several graphene structures. Under normal incidence, the structure's geometric symmetry renders it polarization-insensitive. For TE and TM polarizations up to 15° and 45°, respectively, the structure's absorption and bandwidth are almost indifferent to incident angle. Additionally, The resonant wavelength of a desired plasmonic absorbers can be modified by choosing suitable structural parameters. Due to the simple construction and an absorption maximum tolerance error of 5.12 percent, our spiral absorber has a wider entire at half-maximum of 406 nm, multi-applicant, faultless absorption, and fabrication practicality. The proposed absorber can be used in a variety of applications, including broadband spatial intensity modulators and near-infrared sensors [29].

In [30], Sierpinskinanocarpets with a top silver fractal-like design were used to demonstrate a broadband, polarization-insensitive, wide-angle enormous absorber. Simulation findings showed an average extinction of 0.85 in the spectral area of 400 to 700 nm due to the plasmonic fractal's self-parity feature. Furthermore, the extinction spectra demonstrate significant overlap between TE and TM-polarized electromagnetic waves across a wide range of incidence angles.The underlying process of absorption was physically analyzed using "simulations of magnetic field", "electric field", and "displacement current for the two-base periodicity patterns of the main structure". The broadband absorption profile is caused by"excited cavity modes"," SP modes", and "electric/magnetic dipoles". In sensing and concealing applications, the proposed arrangement has the ability to trap light.

C. Miniaturization

For C-band (4–8 GHz) enforcement, a unit cell is built on an inverted MSKF wide with lumped resistors and a broadband polarization insensitive MMTabsorbers [31]. The proposed structure is installed to stock a wideband at the cost of a 5 mm thick dielectric substrate that is only 0.033o with respect to the lowest operational frequency for use in several contingent applications such as radar cross (RCS) drooping, shielding, electromagneticinterference/electromagnetic compatibility where nomination dimensions can be significantly miniature.One of the most significant parameters to consider when designing an MM absorber for use in a THz MMTis the absorber size. A MM based on fractal Sierpinski curves for dimension lowering and elevationabsorption average is substantive in [32]. By adopting the fractal body as the upper resonators range, a more compact unit cell with a size lowering of 42 percent and twin-frequency operating has been obtained in comparison to the typical square-shaped MA. Furthermore, due to its rotationally symmetrical body, the fractal absorber is polarization insensitive and may operate effectively across a large range of incidence angles. Both the efficient average theory and the multi reflex ion interference theory have been employed to investigate the underlying material mechanism of the proposed THz MA, with the latter proving ineffectual in defining the absorption process of our investigated structure. In the situation of 30° oblique incidences under TE polarization, two absorption peaks were detected at 0.2 and 0.58 THz, with absorptivity of 91 percent and 92.2 percent, respectively. [33] proposes employing a second-order MSK inspired fractal geometry unit cell to produce a compact unit cell absorber with a footprint of 0.11λ. This microwave absorber can be downsized compared to similar microwave absorber cell designs. The structure has a near-perfect absorption peak of 99 percent at 2.45 GHz, which is the operating frequency. He observed that structure can be used to produce absorber arrays in indoor wireless conditions to decrease multipath effects and eliminate eavesdropping attacks as a result of this research

The implementation of MSKF geometry to the absorber stylingresulted in a short RAS model with a substrate thickness of minimal than 0.4 mm, resulting in a MMTabsorber for X-band applications based on MSKF patch design. Many unit cells tuned for ringing at closely separated frequencies were used in a monocular absorber. The findings of the complete wave simulation showed that using dimensionally various fractals strategically positioned on the absorber resulted in a broadband bandwidth [34]. Table1 provide a brief discussion for this study.

DISCUSSION

This study discusses how to create an absorber for radio, microwave, or TZ applications utilizing MMT and fractal geometry. The use of a MMT in the construction of absorbers resulted in a broad absorption band, but the size of the absorber remained the major issue. The similarity and space fulling features of a fractal shape can eliminate or offer multi band, or both to enhance MA, in addition to increasing bandwidth. According to a review, designing a fractal-based MMT absorber can improve overall performance.

CONCLOSION

Research outlined the processes and strategies employed for categorizing MMT absorber based on fractal geometry, as well as their advantages and disadvantages. The methodology review will help researchers choose the best methods for design absorber for different applications in electromagnetic spectrum to enhance the absorber performance based on increasing the bandwidth or using this methods of design to provide multiband or broadband or for absorber size miniaturization.

REFERENCES

[1] Eswaraiah V, Sankaranarayanan V, Ramaprabhu S. Functionalized graphene–PVDF foam composites for EMI shielding. Macromolecular Materials and Engineering. 2011;296:1-5

[2] Wu Z, Li M. Electromagnetic interference shielding of carbon nanotube macrofilms. Scripta Materialia. 2011;64:809-812

[3] Saville P. Review of radar absorbing materials. Defence R&D Canada–Atlantic, Technical Memorandum, DRDC Atlantic TM. 2005;2005-003

[4] Vinoy KJ, Jha RM. Radar Absorbing Materials: From theory to Design and Characterization. Boston: Kluwer Academic Publishers; 1996

[5] Ren, J., Gong, S., Jiang, v.: Low-RCS Monopolar Patch Antenna Based on Dual-Ring Metamaterial Absorber. IEEE Antennas and Wireless Propagation Letters (2017)

[6] Zhong, S., Wu, L., Liu, T., Huang, J., Jiang, W., MA, Y. "Transparent Transmission-selective RADARInfrared Bi-Stealth Structure. Optics Express, 26(13) (2018).

[7] H. Tao, N. I. Landy, C. M. Bingham, X. Zhang, R. D. Averitt, and W. J. Padilla, "A metamaterial absorber for the terahertz regime: Design, fabrication and characterization," Opt. Express 16, 7181-7188 (2008).

[9] Y. Avitzour, Y. A. Urzhumov, and G. Shvets, "Wide-angle infrared absorber based on a negative-index plasmonic metamaterial," Phys. Rev. B 79, 045131 (2009).

[10] N. I. Landy, C. M. Bingham, T. Tyler, N. Jokerst, D. R. Smith and W. J. Padilla, "Design, theory, and measurement of a polarization-insensitive absorber for terahertz imaging," Phys. Rev. B 79, 125104 (2009).

[11] R. Huang, Z. W. Li, L. B. Kong, L. Liu, and S. Matitsine, "Analysis and design of an ultrathin metamaterial absorber," Progress In Electromagnetic Research B 14, 407-429 (2009).

[12] B. Wang, T. Koschny, and C. M. Soukoulis, "Wide-angle and polarization-independent chiral metamaterial absorber," Phys. Rev. B, 80, 033108 (2009).

[13] Y. Q. Ye, Y. Jin, and S. L. He, "Omnidirectional, polarization-insensitive and broadband thin absorber in the terahertz regime," J. Opt. Soc. Am. B 27, 498-504 (2010)

[14] Q. Y. Wen, H. W. Zhang, Y. S. Xie, Q. H. Yang, and Y. L. Liu, "Dual Band Terahertz Metamaterial Absorber: Design, fabrication, and characterization," Appl. Phys. Lett. 95, 241111 (2009)

[15] Q. Y. Wen, Y. S. Xie, H. W. Zhang, Q. H. Yang, Y. X. Li, and Y. L. Liu, "Transmission line model and fields analysis of metamaterial absorber in the terahertz band," Opt. Express 17, 20256–20265 (2009)

[16] H. T. Chen, W. J. Padilla, J. M. O. Zide, A. C. Gossard, A. J. Taylor, and R. D. Averitt, "Active terahertz metamaterials devices," Nature, 444, 597 (2006)

[17] Jiu R et al. Complex permittivity, permeability and electromagnetic wave absorption of α-Fe/C(amorphous) and Fe2B/C(amorphous) nanocomposites. Journal of Physics D: Applied Physics. 2004;37:2737-2741.

[18] Mandelbrot, B. B., "The Fractal Geometry of Nature", W. H. Freeman, San Francisco, CA, 1982.

[19] Kenneth Falconer,"Fractal Geometry: Mathematical Foundations and Application", Second Edition, John Wiley & Sons, Ltd, 2003.

[20] Fawwaz J. Jibrael and Zahraa F. Mizeel, "Comparison of the Radiation Characteristics of Triangular and Quadratic Koch Fractal Dipole Wire Antennas", Iraqi Society for Alternative and Renewable Energy Sources and Techniques 18 (I.S.A.R.E.S.T.), 2009.

[21] Fan, S., & Song, Y. (2018). Bandwidth-enhanced polarization-insensitive metamaterial absorber based on fractal structures. Journal of Applied Physics, 123(8).

[22] Liu, H. B., Hu, C. X., Wang, Z. L., Zhang, H. F., & Li, H. M. (2021). An Ultra-Wideband Terahertz Metamaterial Absorber Based on the Fractal Structure. Plasmonics, 16(1). 2021

[23] Guo, Q., & Hao, F. (2021). Comments on "Wideband Microwave Absorber Comprising

Metallic Split-Ring Resonators Surrounded with E-Shaped Fractal Metamaterial.” IEEE Access, 9, 121302–121304. 2021.

[24] Bilal, R. M. H., Saeed, M. A., Choudhury, P. K., Baqir, M. A., Kamal, W., Ali, M. M., & Rahim, A. A. (2020). Elliptical metallic rings-shaped fractal metamaterial absorber in the visible regime. Scientific Reports, 10(1), 1–12.

[25] Chen, T., Li, S. J., Cao, X. Y., Gao, J., & Guo, Z. X. (2019). Ultra-wideband and polarization-insensitive fractal perfect metamaterial absorber based on a three-dimensional fractal tree microstructure with multi-modes. Applied Physics A: Materials Science and Processing, 125(4), 2019.

[26] Wu, T. K. (2015). Novel metamaterial absorber with fractal elements. IEEE Antennas and Propagation Society, AP-S International Symposium (Digest), 2015-Octob, 244–245.

[27] Cheng, Y. Z., Nie, Y., & Gong, R. Z. (2013). Design of a wide-band metamaterial absorber based on fractal frequency selective surface and resistive films. Physica Scripta, 88(4).

[28] Venneri, F., Costanzo, S., & Borgia, A. (2019). A dual-band compact metamaterial absorber with fractal geometry. Electronics (Switzerland), 8(8), 2–9.

[29] Mohammad S. Zare, N. Nozhat,M.Khodadadi,“Wideband Graphene-Based Fractal Absorber and its Applications as Switch and Invertero”, Springer, January2021.

[30] Dorche, A. E., Abdollahramezani, S., Chizari, A., &Khavasi, A. (2016). Broadband, polarization-insensitive, and wide-angle optical absorber based on fractal plasmonics. IEEE Photonics Technology Letters, 28(22), 2545–2548.

[31] P. Munaga, S. Ghosh, S Bhattacharyya and K. V. Srivastava, A Fractal – based compact broadband polarization insensitive metamaterial absorber using lumped resistors, MICROWAVE AND OPTICAL TECHNOLOGY LETTERS / Vol. 58, No. 2,2015.

[32] Ma, Y., Zhang, H., Li, Y., & Wang, Y. (2014). Miniaturized and dual-band metamaterial absorber with fractal Sierpinski structure. Journal of the Optical Society of America B, 31(2), 325.

[33] AgbaezeEteng, A. (2021). Design of a Compact Fractal Unit Cell Absorber for the 2.45 GHz Band. International Journal of Wireless and Microwave Technologies, 11(1), 15–21.

[34] Dileep, A., Abhilash, P. V., Joy, V., Singh, H., & Nair, R. U. (2020). Metamaterial Absorber based on Minkowski Fractal Patch for Stealth Applications. Proceedings of CONECCT 2020 - 6th IEEE International Conference on Electronics, Computing and Communication Technologies, 31–34.