

## Advances in Structural Design and High-Temperature Resistance and Broadband EMW Radar Absorbers Based on CMM Material

Haniya D. Ali <sup>1</sup>, Abdulaziz H. Daw <sup>2\*</sup>

<sup>1,2</sup> College of Electronics Technology, Bani Walid, Libya

\*Email (for reference researcher): [abdulaziz.d@cetb.edu.ly](mailto:abdulaziz.d@cetb.edu.ly)

تطورات في التصميم الهيكلي ومقاومة درجات الحرارة العالية وماصات الرادار للموجات الكهرومغناطيسية (EMW) واسعة النطاق المعتمدة على مادة CMM

هنية الدهماني علي <sup>1</sup>، عبد العزيز حسن ضو <sup>2\*</sup>

<sup>2,1</sup> كلية التقنية الإلكترونية، بني وليد، ليبيا

Received: 15-01-2026; Accepted: 17-03-2026; Published: 07-04-2026

### Abstract:

Ceramic metamaterial (CMM) based metamaterials, which are artificial materials designed to have unique electromagnetic or thermal properties. These CMMs are often explored for their advantages like low dielectric loss, high-temperature resistance, and tenable performance, making them promising for applications in areas such as millimetre-wave devices, high-temperature sensors, and absorbers. Usually have the characteristics of lightweight, high specific stiffness and strength, controllable Poisson's ratio designable anisotropy, etc. They can meet the requirements of multiple functions while meeting the load-bearing performance. They can be used as structural support materials, energy absorption materials, noise reduction materials, thermal conductivity materials, and biological materials, and have broad application prospects in aviation, navigation, medicine, and etc. Currently, the performance of common radar absorbers deteriorates dramatically at elevated temperatures, which limits their application in high-temperature environments. for broadband microwave absorption. In the CMM, which exhibits excellent electromagnetic (EM) wave polarization stability properties. This work may assist in the design and manufacture of a new generation of radars, ships, and aircraft will be evaluated using (HFSS) software (Vs. 15).

**Keywords:** ceramics; EMW; absorbing; metamaterial; 3D printing; high temperature resistance and HFSS.

### المخلص

تُعد المواد الخارقة القائمة على السيراميك (CMM) مواداً اصطناعية مصممة لامتلاك خصائص كهرومغناطيسية أو حرارية فريدة. غالباً ما يتم استكشاف هذه المواد (CMMs) نظراً لمزاياها المتعددة، مثل انخفاض الفقد العازل (dielectric loss)، والمقاومة العالية لدرجات الحرارة، والأداء القابل للضبط، مما يجعلها واعدة للتطبيقات في مجالات مثل أجهزة الموجات المليمترية، وأجهزة الاستشعار عالية الحرارة، والماصات.

تتميز هذه المواد عادةً بخفة الوزن، والصلابة والقوة النوعية العالية، ونسبة "بواسون" القابلة للتحكم، والتباين الموجه (anisotropy) القابل للتصميم، وغير ذلك. كما يمكنها تلبية متطلبات الوظائف المتعددة مع الحفاظ على أداء تحمل الأحمال؛ حيث يمكن استخدامها كمواد دعم هيكلية، ومواد لامتصاص الطاقة، وتقليل الضوضاء، ومواد للتوصيل الحراري، ومواد حيوية، مما يمنحها آفاقاً تطبيقية واسعة في مجالات الطيران، والملاحة، والطب، وغيرها.

حالياً، يتدهور أداء ماصات الرادار الشائعة بشكل حاد عند ارتفاع درجات الحرارة، مما يحد من استخدامها في البيئات الحرارية العالية لامتصاص الموجات الدقيقة (Microwave) واسعة النطاق. وفي المقابل، تُظهر مادة (CMM) خصائص ممتازة في استقرار استقطاب الموجات الكهرومغناطيسية (EM). قد يساهم هذا العمل في دعم تصميم وتصنيع جيل جديد من أجهزة الرادار والسفن والطائرات، وسيتم تقييم النتائج باستخدام برنامج (HFSS) الإصدار (15).

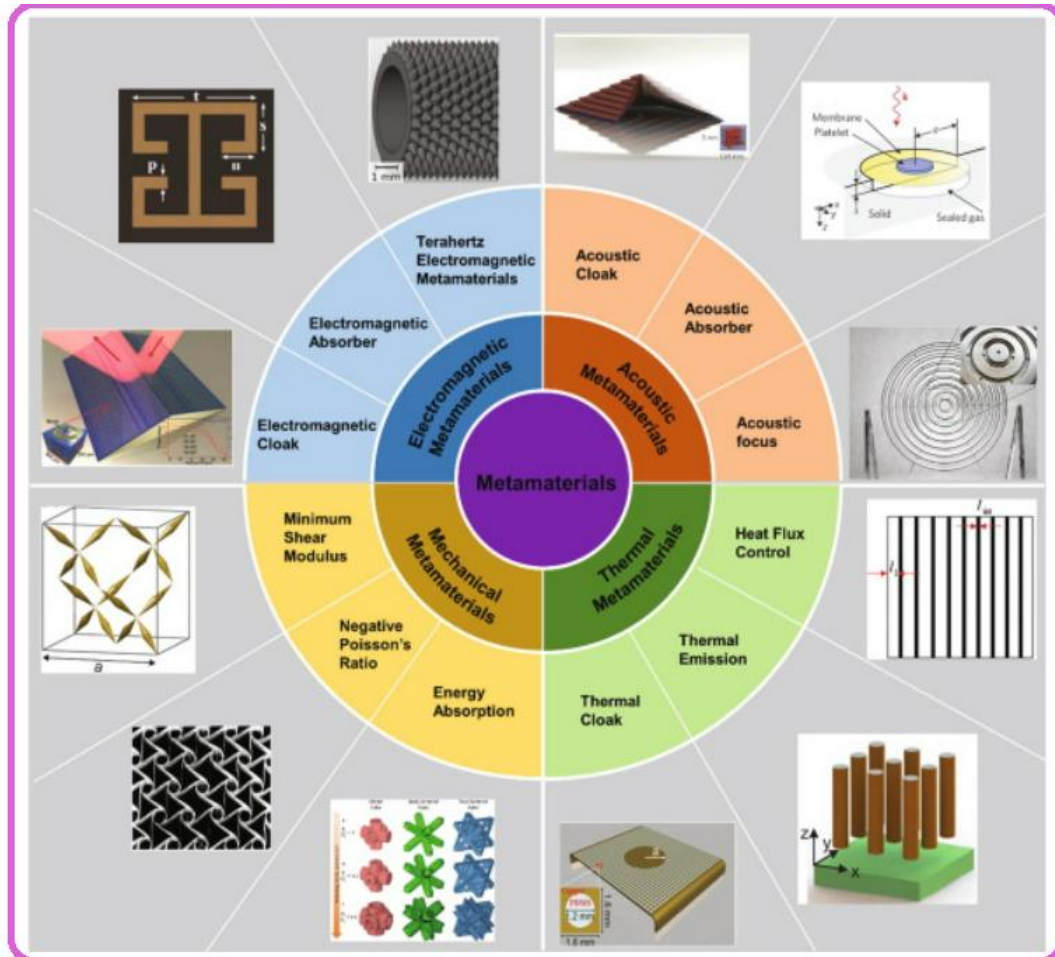
**الكلمات المفتاحية:** السيراميك، الموجات الكهرومغناطيسية، الامتصاص، المواد الخارقة، الطباعة ثلاثية الأبعاد، مقاومة درجات الحرارة العالية، برنامج HFSS.

### Introduction

Ceramic metamaterial (CMM) acted considerable attention recently [19][9][30][4][5], and they have great application potential for structures or devices working at high temperatures or over a large temperature range in aerospace and high-temperature instrument applications. For instance, the satellite antennas and their supporting structures used in earth-orbiting satellites typically cycle between direct sunlight to shadow [21]. When EM waves enter the material surface, reflection, transmission, and absorption will occur on the material surface [4,8]. The basic principle of EM

absorbing materials is to reduce the reflection and transmission of EM waves and increase the absorption inside the material. For non-magnetic materials, the complex dielectric constant  $\epsilon$  is the key parameter that determines their properties, as shown below ( $\epsilon = \epsilon' - j \epsilon''$ ). Similarly, the wave-absorbing properties of magnetic materials depend on structure EM wave absorption materials, temperature-Resistant microwave absorbing material, shown figure1.

Figure 1. High-temperature-resistant ceramic materials for absorbing microwaves [10,11,3, 6]. Reproduced with permission from Ref. [21]. Copyright 2016, Elsevier. Reproduced with permission from Ref. [31]. Copyright 2015, American Chemical Society. Reproduced with permission from Ref. [10]. Copyright 2020, Elsevier. Reproduced with permission from Ref. [10]. Copyright 2013, The American Ceramic Society. Reproduced with permission from Ref.



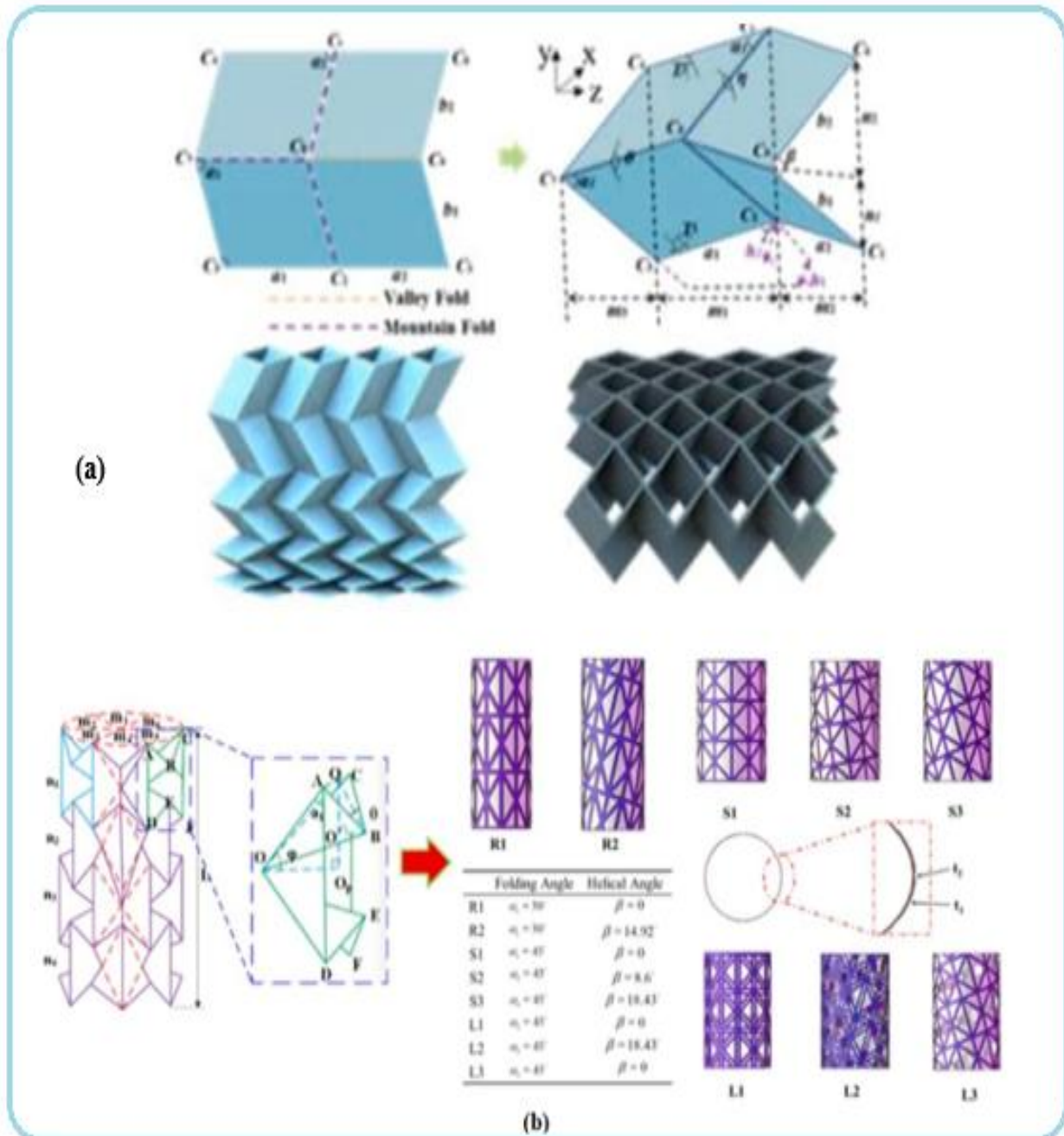
**Figure 1:** The classification of MMs based on their functionalities.

Wave-absorbing metamaterials regulate their equivalent electromagnetic parameters via the design of the structure of the material cell [21], thus achieving good impedance matching with free space, opening up new opportunities for EMW-absorbing materials to achieve significant absorption properties at specific or wide frequencies [5,23,11,3,6]. Wave-absorbing metamaterials overcome the bottleneck of traditional wave-absorbing materials in low frequency bands. They also possess strong absorption, small thickness, a flexible design, light weight, etc., all of which mean they have great potential application value in stealth technology. Traditional ceramic processing methods like powder sintering make it difficult to meet the design requirements of flexible and complex structural units of absorbent metamaterial structures; their manufacturing process is complex, and their cost is high [1,4]. Figure 2(a) shows metamaterials designed for energy absorption. It demonstrates basic folding principles, such as valley and mountain folds, and how these are used to create accordion-like structures. Figure 2(b) focuses on the design of origami mechanical metamaterials with a high absorption ratio. It details various structural designs (R1, R2, S1, S2, S3, L1, L2 and L3) and their respective folding and helical angles. These configurations are intended to optimise the energy absorption properties of the metamaterials.

As a highly flexible manufacturing technology [13], 3D printing technology has the strengths of a high material utilization rate, a rich material system, easy-to-form complex parts, and low cost, and it can achieve the fast processing of three-dimensional complex metamaterial structures. The integrated manufacturing of functional

structures made of high-temperature-absorbing ceramic metamaterials with complex electromagnetic control functions has been explored for use in the future [6,9].

To ensure the electromagnetic compatibility of high-precision communication satellites in high-radiation environments, ceramic-based absorbent liners are typically installed inside satellite equipment to absorb reflected electromagnetic waves and prevent interference with the signals of internal devices [5].



**Figure 2:** a) Origami mechanical metamaterials for energy-absorbing [30] (b) Design of origami mechanical metamaterial with high absorption ratio [31].

### Design of microwave-absorbing materials

EMW-absorbing materials can convert incident EMWS into heat through electromagnetic loss, with extremely low reflectivity and transmittance. The transmission process of the incident EMW in the medium is shown in schematic figure 3.

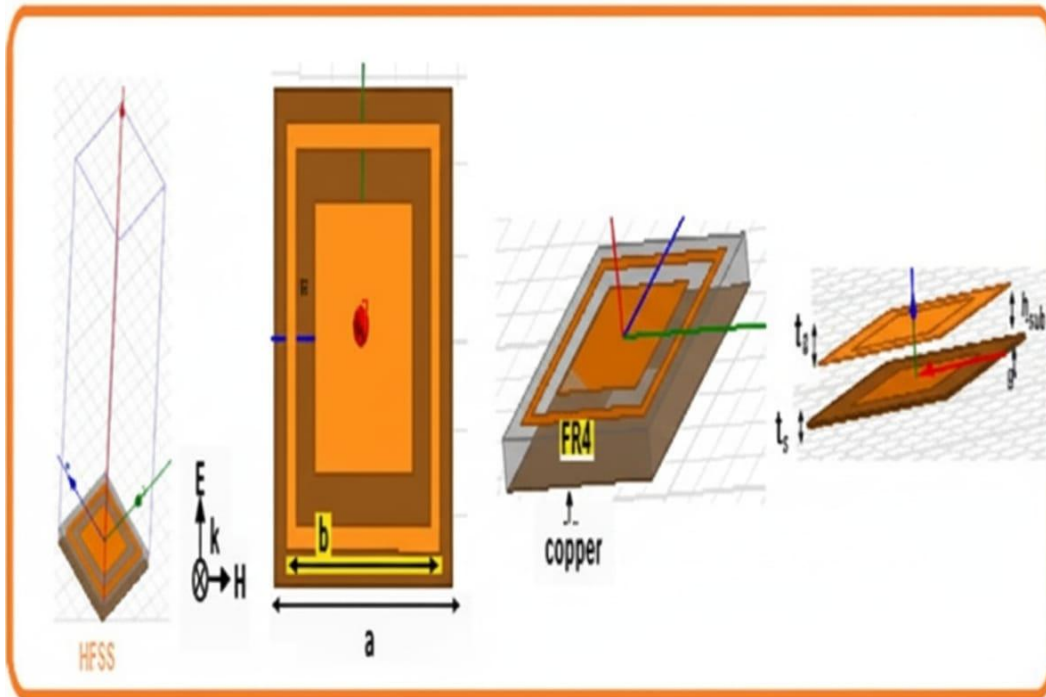


Figure 3: Geometry of the initial absorber design.

Figure 3 illustrates the geometry of the top view and (b) side view of the unit cell with geometrical dimensions as:  $a = 16\text{mm}$ ,  $b = 9\text{mm}$ ,  $w = 2.2\text{mm}$ ,  $t_{\text{air}} = 0.05\text{mm}$ ,  $t_{\text{air}} = 4\text{mm}$ ,  $t = 0.3\text{mm}$  and  $t_c = 0.017\text{mm}$ .

The ratios of the reflected, the absorbed, and the transmitted to the incident EMW are defined as reflectance (R), absorbance (A), and transmittance (T), respectively. The absorbance is expressed as follows [10].

**Results and discussion**

Figure 4 displays the Ceramic-based absorbing materials.

Figure 5 shows that the input impedance for low dielectric constant (Air), best material (from result Styrofoam) and greater material (Mica) show variation with increasing relative permittivity.

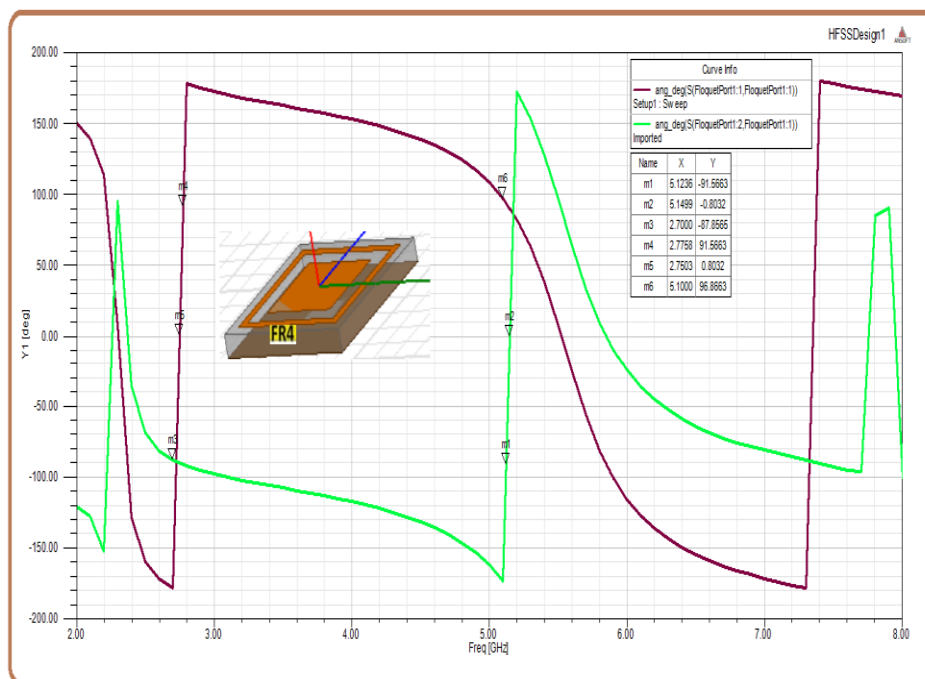


Figure 4: Geometry of the initial absorber design.

In figure 4 complex metamaterial structures. The integrated manufacturing of functional structures made of high-temperature-absorbing ceramic metamaterials with complex electromagnetic control functions.

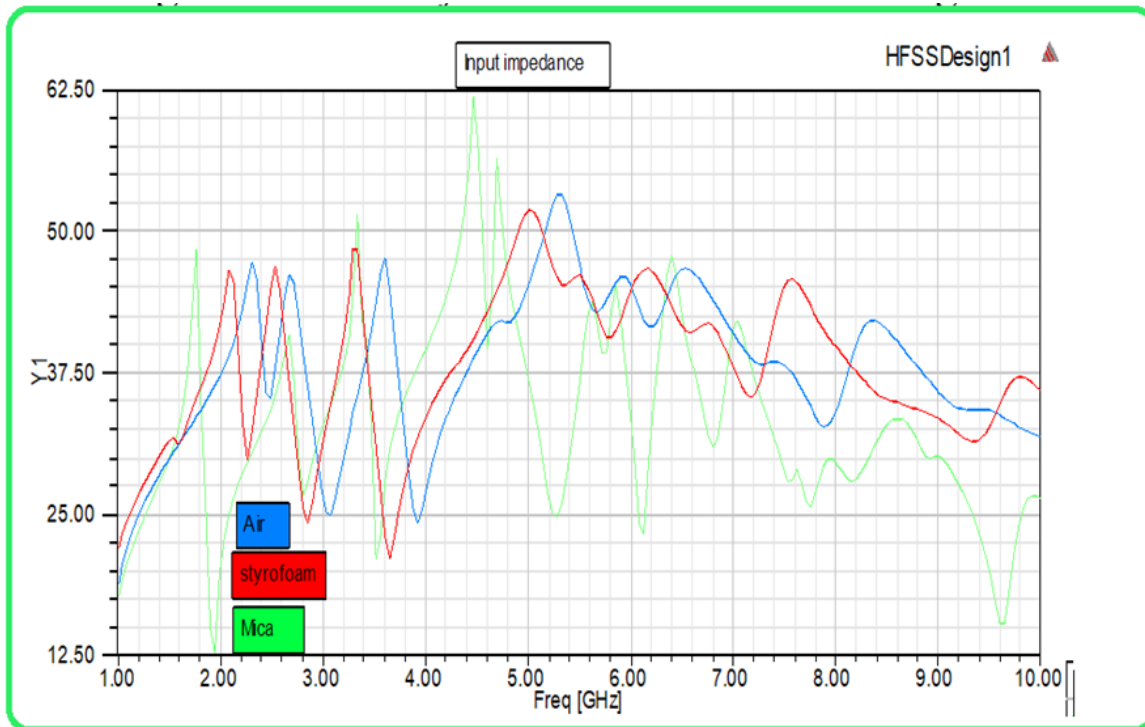


Figure 5: input impedance for three metamaterials.

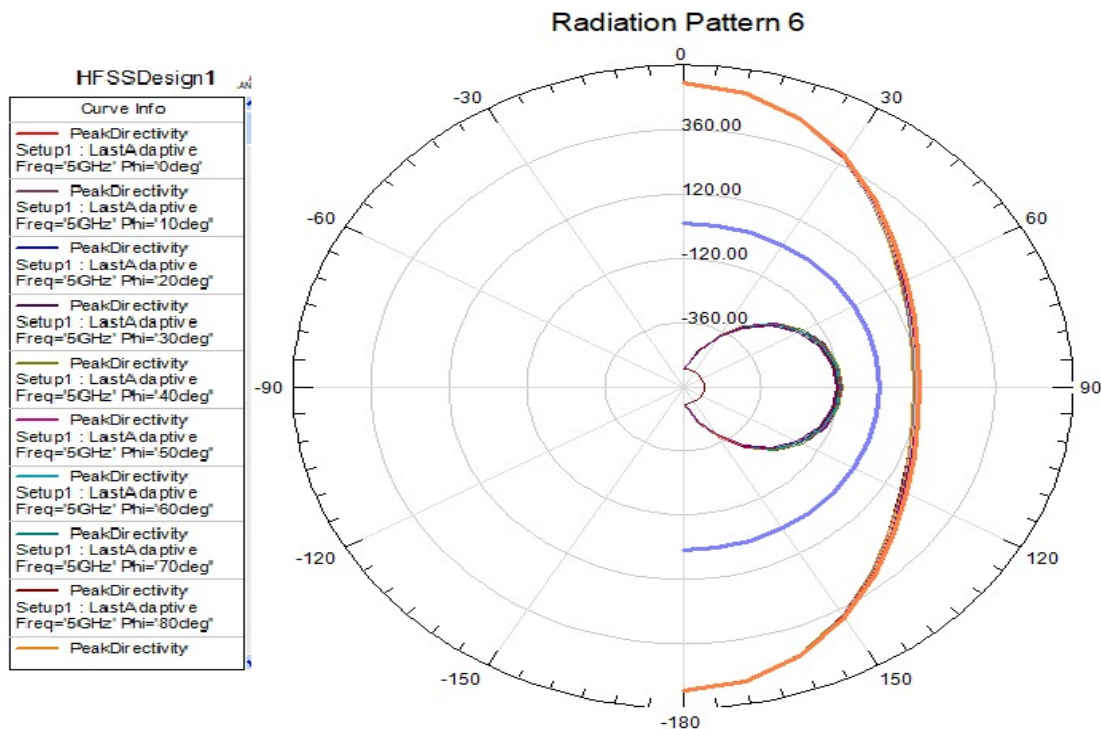


Figure 6: Radiation pattern.

A radiation pattern is a graph showing how the actual field strength of an electromagnetic field varies at all points equidistant from an antenna. The radiation pattern graph (Figure 6) illustrates the directions of the radiation pattern.

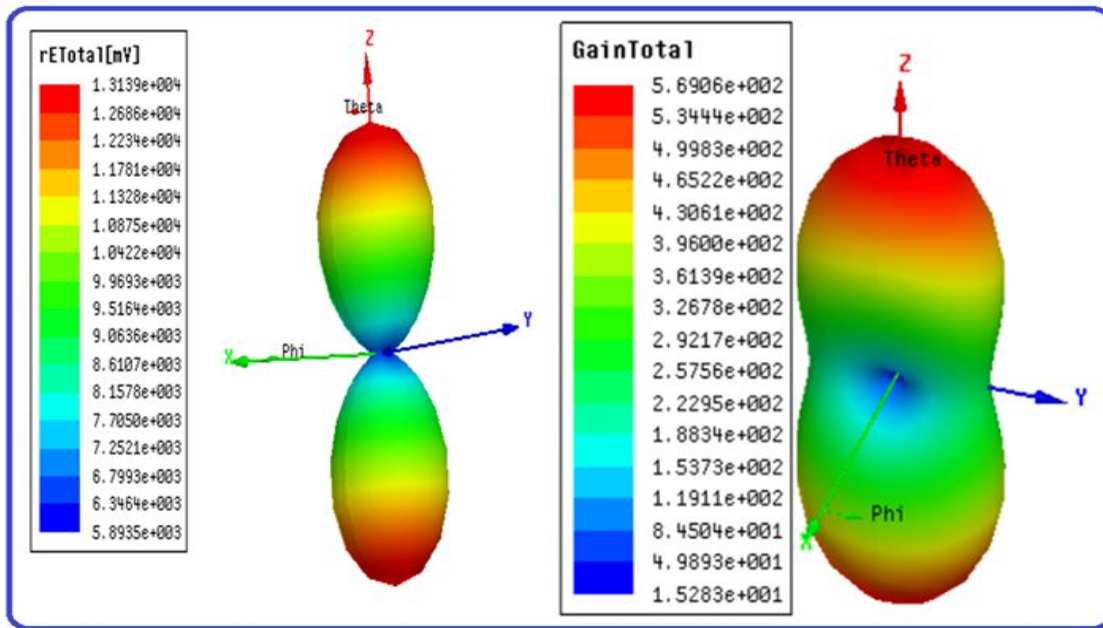


Figure 7: Gain in 3D.

Figure 7 below illustrates the total gain of the antenna for various substrate materials. Using Styrofoam as the substrate material yields a gain of 8.38 dB.

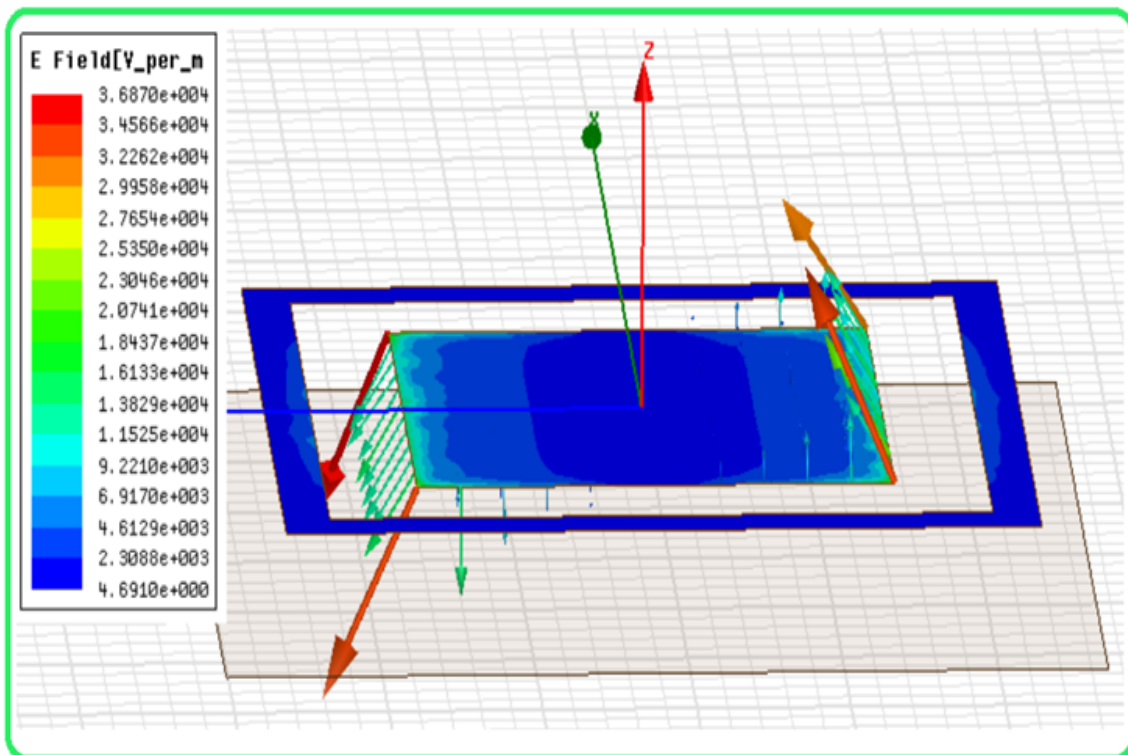


Figure 8: Calculated current distribution on the unit cell.

Figure 8 illustrates the calculated current distribution and demonstrates the impact of the dielectric constant in the unit cell on the surface current density. In other words, it shows how the current

density in an extended unit cell along the patch resonant dimension is affected by the dielectric constant in the unit cell.

## Conclusion

In this paper, the importance of substrate selection has been remarked upon in the context of the overall description of radiation and losses in an absorbed unit cell metamaterial. Its permittivity determines the overall length, Research on EM wave-absorbing materials has progressed rapidly in recent years. There is an increasing focus on achieving efficient, broadband, lightweight and multifunctional absorption through the integration of material design, structural control and advanced fabrication, with conventional empirical approaches being replaced by simulation.

## References

1. Cai, X. B., Guo, Q. Q., Hu, G. K., & Yang, J. (2014). Ultrathin low-frequency sound absorbing panels based on coplanar spiral tubes or coplanar Helmholtz resonators. *Applied Physics Letters*, 105(12), 121901.
2. Dudek, K. K., Attard, D., Caruana-Gauci, R., Wojciechowski, K. W., & Grima, J. N. (2016). Unimode metamaterials exhibiting negative linear compressibility and negative thermal expansion. *Smart Materials and Structures*, 25(2), 25009.
3. Esfahlani, H., Lissek, H., & Mosig, J. R. (2017). Generation of acoustic helical wavefronts using metasurfaces. *Physical Review B*, 95(2), 024312.
4. Fan, C. Z., Gao, Y., & Huang, J. P. (2008). Shaped graded materials with an apparent negative thermal conductivity. *Applied Physics Letters*, 92(25), 251907.
5. Grima, J. N., Cassar, R. N., & Gatt, R. (2009). On the effect of hydrostatic pressure on the auxetic character of NAT-type silicates. *Journal of Non-Crystalline Solids*, 355(24–27), 1307–1312.
6. Guenneau, S., Amra, C., & Veynante, D. (2012). Transformation thermodynamics: cloaking and concentrating heat flux. *Optics Express*, 20(7), 8207–8218.
7. Guo, X. G., Ni, X. Y., Li, J. H., Zhang, H., Zhang, F., Yu, H. B., et al. (2021). Designing mechanical metamaterials with kirigami-inspired, hierarchical constructions for giant positive and negative thermal expansion. *Advanced Materials*, 33(3), e2004919.
8. Huang, Y. Y., Yao, Z. H., Hu, F. R., Liu, C. J., Yu, L. L., Jin, Y. P., et al. (2017). Tunable circular polarization conversion and asymmetric transmission of planar chiral graphene-metamaterial in terahertz region. *Carbon*, 119, 305–313.
9. Li, Y., Liang, B., Tao, X., Zhu, X. F., Zou, X. Y., & Cheng, J. C. (2012). Acoustic focusing by coiling up space. *Applied Physics Letters*, 101(23), 23350.
10. Li, Y., Jiang, X., Li, R. Q., Liang, B., Zou, X. Y., Yin, L. L., et al. (2014). Experimental realization of full control of reflected waves with subwavelength acoustic metasurfaces. *Physical Review Applied*, 2, 064002.
11. Liu, J., Li, L. P., Xia, B. Z., & Man, X. F. (2018). Fractal labyrinthine acoustic metamaterial in planar lattices. *International Journal of Solids and Structures*, 132–133, 20–30.
12. Liu, R. P., Ji, C., Mock, J. J., Chin, J. Y., Cui, T. J., & Smith, D. R. (2009). Broadband ground-plane cloak. *Science*, 323(5912), 366–369.
13. Lu, Z., Wang, Q. S., Li, X., & Yang, Z. Y. (2017). Elastic properties of two novel auxetic 3D cellular structures. *International Journal of Solids and Structures*, 124, 46–56.
14. Ni, X. Y., Guo, X. G., Li, J. H., Huang, Y. G., Zhang, Y. H., & Rogers, J. A. (2019). 2D mechanical metamaterials with widely tunable unusual modes of thermal expansion. *Advanced Materials*, 31(48), 1905405.
15. Nicolaou, Z. G., & Motter, A. E. (2012). Mechanical metamaterials with negative compressibility transitions. *Nature Materials*, 11, 608–613.
16. Schaedler, T. A., Jacobsen, A. J., Torrents, A., Sorensen, A. E., Lian, J., Greer, J. R., et al. (2011). Ultralight metallic microlattices. *Science*, 334(6058), 962–965.
17. Schittny, R., Kadic, M., Guenneau, S., & Wegener, M. (2013). Experiments on transformation thermodynamics: molding the flow of heat. *Physical Review Letters*, 110(19), 195901.
18. Schurig, D., Mock, J. J., Justice, B. J., Cummer, S. A., Pendry, J. B., Starr, A. F., & Smith, D. R. (2006). Metamaterial electromagnetic cloak at microwave frequencies. *Science*, 314(5801), 977–980.
19. Shan, S. C., Kang, S. H., Raney, J. R., Wang, P., Fang, L. C., Candido, F., et al. (2015). Multistable architected materials for trapping elastic strain energy. *Advanced Materials*, 27(29), 4296–4301.

20. Shen, S., Henry, A., Tong, J., Zheng, R. T., & Chen, G. (2010). Polyethylene nanofibres with very high thermal conductivities. *Nature Nanotechnology*, 5(4), 251–255.
21. Smith, C. W., Grima, J. N., & Evans, K. E. (2000). A novel mechanism for generating auxetic behavior in reticulated foams: missing rib foam model. *Acta Materialia*, 48(17), 4349–4356.
22. Song, Y. G., Cheng, Q., Huang, B., Dong, H. Y., & Cui, T. J. (2016). Broadband fractal acoustic metamaterials for low-frequency sound attenuation. *Applied Physics Letters*, 109(13), 131901.
23. Wu, L. L., Xi, X. Q., Li, B., & Zhou, J. (2018). Multi-stable mechanical structural materials. *Advanced Engineering Materials*, 20(2), 1700599.
24. Xin, X. Z., Liu, L. W., Liu, Y. J., & Leng, J. S. (2020). 4D printing auxetic metamaterials with tunable, programmable, and reconfigurable mechanical properties. *Advanced Functional Materials*, 30(43), 2004226.
25. Yang, Z. J., Gao, F., Shi, X. H., Lin, X., Gao, Z., Chong, Y. D., et al. (2015). Topological acoustics. *Physical Review Letters*, 114(11), 114301.
26. Yue, C. B., Zhao, W., Li, F. F., Liu, L. W., Liu, Y. J., & Leng, J. S. (2023). Shape recovery properties and load-carrying capacity of a 4D printed thick-walled kirigami-inspired honeycomb structure. *Bio-Design and Manufacturing*, 6, 189–203.
27. Zhang, H., Wu, J., Zhang, Y. H., & Fang, D. N. (2021). Multi-stable mechanical metamaterials: A brief review. *Transactions of Nanjing University of Aeronautics and Astronautics*, 38(1), 1–17.
28. Zhao, W., Li, N., Liu, L. W., Leng, J. S., & Liu, Y. J. (2022). Origami derived self-assembly stents fabricated via 4D printing. *Composite Structures*, 293, 115669.
29. Zhao, W., Li, N., Liu, X., Liu, L. W., Liu, Y. J., & Leng, J. S. (2023). 4D printed shape memory metamaterials with sensing capability derived from the origami concept. *Nano Energy*, 115, 108697.
30. Zhong, J., Zhao, H. G., Yang, H. B., et al. (2019). Theoretical requirements and inverse design for broadband perfect absorption of low-frequency waterborne sound by ultrathin metasurface. *Scientific Reports*, 9, 1181.
31. Zhu, X. F., Li, K., Zhang, P., Zhu, J., Zhang, J. T., Tian, C., et al. (2016). Implementation of dispersion-free slow acoustic wave propagation and phase engineering with helical-structured metamaterials. *Nature Communications*, 7(1), 11731.

**Disclaimer/Publisher's Note:** The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of **LOUJAS** and/or the editor(s). **LOUJAS** and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.