SINTECHCOM: Science, Technology and Communication Journal
Vol. 6, No. 2, February 2026, pp. 105-112, DOI: 10.59190/stc.v6i2.340

Ultra-wideband diamond-shaped metamaterial absorber for radar cross section reduction

Defrianto[1], Erwin Kurnia[1], Saktioto[1,*], Tengku Emrinaldi[1], Feby Nur Sakinah[1], M Ikhsan[1], Vepy Asyana[1,2,3], Yan Soerbakti[1]
[1]Department of Physics, Universitas Riau, Pekanbaru 28293, Indonesia
[2]Department of Physics, Institut Teknologi Bandung, Bandung 40132, Indonesia
[3]Department of Physics, Kyushu University, Fukuoka 819-0395, Japan

ABSTRACT

This study presents the design and full-wave simulation of a diamond-shaped metamaterial absorber configured in a 4×4 array for applications in radar cross section reduction (RCSR). The structure was modeled on an FR-4 substrate with a copper patch and metallic ground plane to achieve high absorption across the ultra-wideband (UWB) frequency range of 0.09 – 10 GHz. Simulations were conducted using CST Studio Suite. Key radar-related performance parameters including reflection (S11), transmission (S21), and absorption were analyzed. Results indicate that the absorber achieves extremely low reflection values (return loss up to -85 dB), near-zero transmission due to the ground plane, and absorption exceeding 80% in targeted radar bands. These findings demonstrate the high potential of diamond-shaped metamaterial absorbers for stealth applications and electromagnetic wave attenuation in modern radar systems.

ARTICLE INFO

Article history:

Received Nov 17, 2025
Revised Feb 12, 2026
Accepted Feb 18, 2026

Keywords:

Array Coupling
Resonant Frequency
Scattering Reduction
Split-Ring Resonator
Waveguide

* **Corresponding Author**
E-mail address: saktioto@lecturer.unri.ac.id

1. INTRODUCTION

Radar cross section (RCS) represents a key physical quantity that determines how detectable an object is by a radar system. A higher RCS indicates stronger backscattered electromagnetic waves, thereby increasing the probability of detection by hostile or surveillance radar [1-5]. In modern military, aviation, and maritime applications, reducing RCS has become an essential strategy for enhancing stealth performance and operational survivability. Various technologies have been developed to achieve RCS reduction, including shaping techniques, resistive coatings, frequency-selective surfaces, and radar absorbing materials (RAM). However, many conventional RAMs suffer from disadvantages such as narrow bandwidth, high thickness, heavy weight, and limited electromagnetic tunability [6, 7].

Metamaterials engineered structures with customized electromagnetic responses unattainable in natural media offer an advanced platform for developing next-generation radar absorbers. Their sub-wavelength resonant inclusions enable precise manipulation of reflection, transmission, and energy dissipation across specific frequency bands [8-12], making them promising candidates for broadband RCS reduction. Metamaterial absorbers, in particular, have attracted significant interest since the introduction of perfect absorbers that achieve near-unity absorption at resonant frequencies [13, 14]. These absorbers utilize geometrically patterned metallic resonators and dielectric substrates to achieve simultaneous impedance matching and energy dissipation, resulting in strong absorption and minimal backscattering.

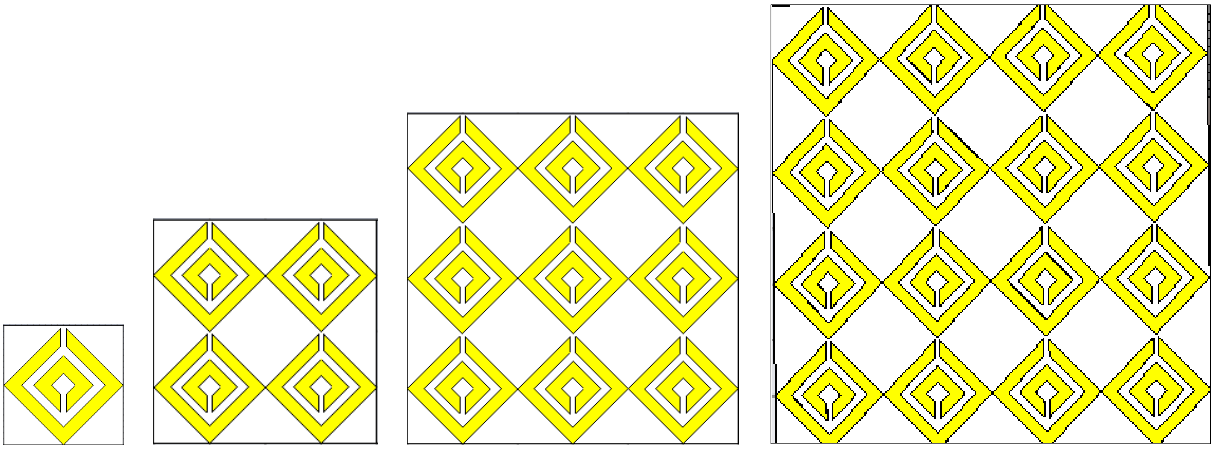
Recent studies have demonstrated that metamaterial absorbers can outperform traditional RAMs due to their thin profile, lightweight structure, flexible fabrication, and wide operational bandwidth [15-19]. Furthermore, by arranging resonant unit cells into multi-element arrays, broadband absorption can be achieved through multi-mode electromagnetic coupling and enhanced field localization [20, 21]. Such characteristics are especially important in ultra-wideband (UWB) radar systems, which operate across a wide spectrum (0.1 – 10 GHz) and are widely used in maritime surveillance, aircraft navigation, and defense radar applications [22-30].

In this context, the present study focuses on the design and simulation of a diamond-shaped metamaterial absorber arranged in a 4×4 array. The proposed structure is fabricated on an FR-4 substrate with a copper patch layer and a ground plane, ensuring near-zero transmission and efficient electromagnetic absorption. Full-wave simulations were conducted using CST Studio Suite to evaluate radar-related performance metrics including reflection (S11), transmission (S21), and absorption. The results show exceptionally low reflection values (up to -85 dB) and high absorption (> 80%) across key radar frequencies, confirming the absorber's suitability for RCS reduction and stealth technology applications.

2. RESEARCH METHODOLOGY

The research methodology consists of several stages involving the design, modeling, and electromagnetic characterization of a diamond-shaped metamaterial absorber intended for radar cross section reduction. All simulations were carried out using CST Microwave Studio Suite 2019, which employs a full-wave finite integration technique to compute the S-parameters of complex electromagnetic structures. The study begins with defining the structural geometry of the unit cell, material parameters, and boundary conditions suitable for mimicking periodic metamaterial behavior.

The absorber was constructed using an FR-4 substrate with a dielectric constant of 4.6 and a thickness of 1.6 mm, corresponding to standard PCB specifications. A copper layer with a thickness of 0.035 mm formed both the patterned resonator on the top surface and the continuous ground plane at the bottom. The resonator adopted a diamond-shaped split-ring configuration, selected for its ability to support multi-resonant behavior and enhance electromagnetic attenuation within the Ultra Wideband (UWB) frequency range. To evaluate array effects, the unit cell was replicated into 1×1, 2×2, 3×3, and 4×4 configurations, with the 4×4 array serving as the primary model for radar applications.



(a) (b) (c) (d)

Figure 1. Array configurations of the diamond-shaped metamaterial structure: (a) 1×1 unit cell, (b) 2×2 array, (c) 3×3 array, and (d) 4×4 array.

Before simulation, appropriate boundary conditions were assigned, perfect electric conductor (PEC) and perfect magnetic conductor (PMC) boundaries were applied to emulate an infinitely periodic structure, while a waveguide port excitation was introduced along the propagation axis. The simulation frequency sweep was set between 0.09 and 10 GHz to cover the operational bands of UWB radar systems. Within CST, the time-domain solver was employed due to its computational efficiency and ability to accurately capture broadband responses across wide frequency ranges.

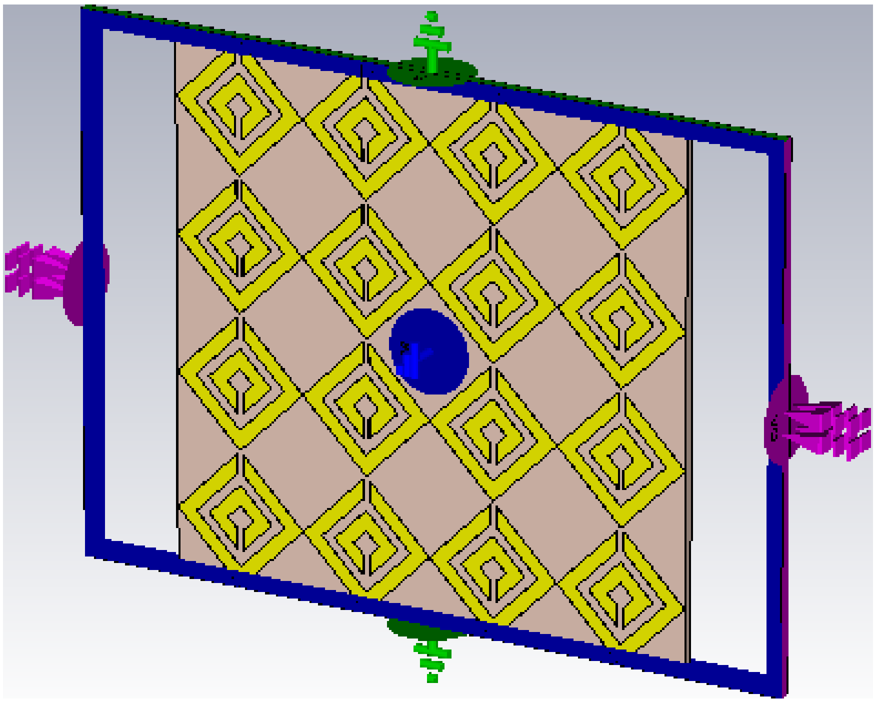


Figure 2. Illustration of the simulation scheme for metamaterial identification with boundary plane locations and excitation plane locations.

After completing the simulations, the scattering parameters S11 (reflection) and S21 (transmission) were extracted for analysis. Since the ground plane blocks all forward transmission, |S21| approaches zero across the entire spectrum. The absorption of the structure was subsequently calculated using the standard relation:

$$A(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2 \tag{1}$$

which simplifies to

$$A(\omega) = 1 - |S_{11}|^2 \tag{2}$$

for a backed absorber. These computed values allowed the characterization of electromagnetic performance in terms of reflection suppression, transmission elimination, and absorption enhancement, which are the main indicators of radar cross section reduction effectiveness.

Finally, the performance of each array configuration was compared to evaluate the influence of array size on resonance broadening, absorption stability, and scattering reduction. The 4×4 array demonstrated the most favorable behavior and was selected for detailed analysis in subsequent sections. All results were exported and plotted using auxiliary software to facilitate qualitative and quantitative interpretation of the radar-related performance metrics.

3. RESULTS AND DISCUSSION

The electromagnetic performance of the diamond-shaped metamaterial absorber was evaluated by analyzing its reflection (S11), transmission (S21), and absorption characteristics across the frequency range of 0.09 – 10 GHz. Full-wave CST simulations were performed for several array configurations, with emphasis on the 4×4 array due to its superior performance in radar cross section reduction. The results reveal that the absorber exhibits distinctive multi-resonant behavior, enabling effective attenuation of incident electromagnetic waves over a broad frequency band relevant to UWB radar systems.

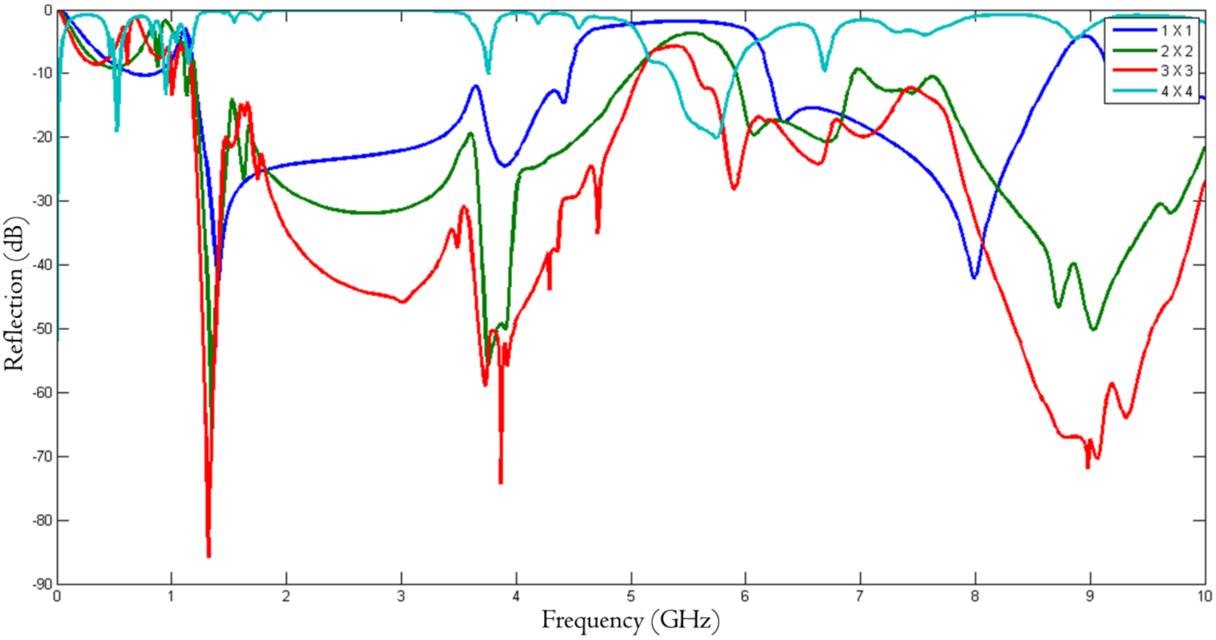


Figure 3. Reflection spectrum versus frequency graph for diamond-shaped metamaterial.

The reflection spectrum (S11) demonstrates the absorber's capability to suppress backscattered radar energy. The 4×4 configuration produced multiple deep reflection minima, with the lowest reaching approximately -85 dB. This extremely low reflection level indicates strong impedance matching between the absorber surface and free space, minimizing electromagnetic energy returning to the radar. As the array size increases from 1×1 to 4×4, the reflection dips become sharper and more distributed, signifying enhanced collective resonance effects. This behavior confirms that array coupling plays a crucial role in broadening the operational bandwidth and improving RCS reduction performance.

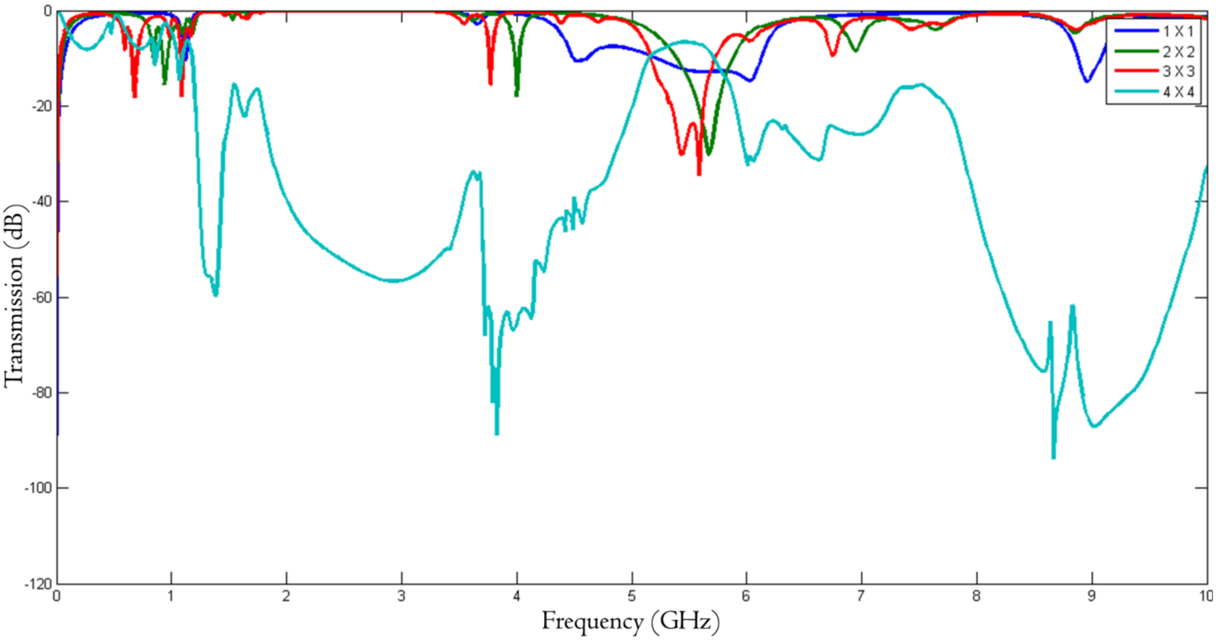


Figure 4. Transmission spectrum versus frequency graph for diamond-shaped metamaterial.

The transmission spectrum (S21) further validates the absorber’s efficiency. Due to the continuous copper ground plane beneath the substrate, transmitted energy is effectively eliminated, resulting in S21 values approaching -200 dB across nearly all frequencies. This indicates that no incident energy penetrates through the structure, and all electromagnetic interactions occur at the absorber’s front surface. The near-zero transmission is essential for radar absorbing materials, as it ensures that the absorber behaves as a perfect terminator for incoming waves rather than allowing leakage that could lead to additional scattering.

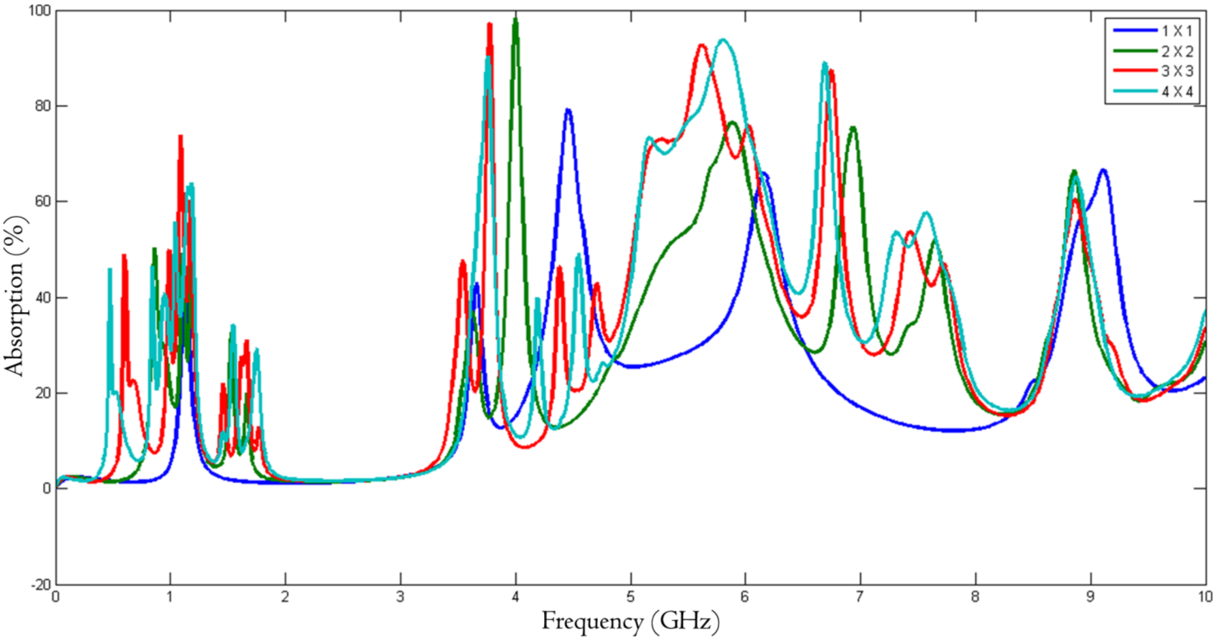


Figure 5. Absorption spectrum versus frequency graph for diamond-shaped metamaterial.

Absorption behavior, computed using Equation (1), shows high absorption efficiency across key radar bands. Since |S21| is negligible, absorption is dominated by reflection suppression. The 4×4 array exhibits absorption values exceeding 80%, with several peaks above 90%, demonstrating strong resonant dissipation of electromagnetic energy. These absorption peaks correspond to the frequencies at which reflection dips occur, indicating efficient conversion of incident wave energy into heat or localized electromagnetic losses within the resonator structure. Moreover, the broadband absorption characteristics confirm the suitability of this metamaterial absorber for Ultra Wideband radar applications, where performance must remain stable over a wide range of operating frequencies.

Overall, the results demonstrate that the diamond-shaped metamaterial absorber effectively suppresses reflection, eliminates transmission, and maximizes absorption across UWB frequencies. The 4×4 array provides the most stable and robust performance due to inter-element coupling and field localization effects. These findings highlight the absorber’s strong potential for Radar Cross Section Reduction in stealth technologies, maritime surveillance, unmanned aerial vehicles (UAVs), and modern electromagnetic defense systems.

4. CONCLUSION

The results of this study demonstrate that the diamond-shaped metamaterial absorber configured in a 4×4 array provides highly effective radar cross section reduction across the Ultra-Wideband frequency range through its ability to suppress reflection, eliminate transmission, and achieve absorption levels exceeding 80% at key resonance frequencies. The extremely low reflection values (down to -85 dB) indicate excellent impedance matching and minimal backscattering, while the presence of a continuous ground plane ensures near-zero transmission, allowing all incident electromagnetic energy to be either absorbed or dissipated within the structure. The broadband and multi-resonant absorption characteristics observed confirm the absorber’s suitability for advanced stealth applications, including maritime, aerospace, and defense systems, where wide-frequency radar attenuation and structural thinness are required. Overall, the findings establish the proposed metamaterial absorber as a strong candidate for practical implementation in modern radar-absorbing technologies.

ACKNOWLEDGMENTS

The authors sincerely acknowledge the financial support provided by Universitas Riau through the Riset Afirmasi (RISI) Research Grant Scheme, under research contract number 38559/UN19.5.1.3/AL.04/2025. This funding has been essential in enabling the successful execution of this study. The authors also extend their appreciation to all colleagues, laboratory staff, and institutional partners who contributed technical assistance and insight throughout the research process.

REFERENCES

[1] Shittu, I., Abou-Khousa, M., Viegas, J., Hernandez-Figueroa, H. E., & Elfadel, I. M. (2025). Radar cross section reduction metamaterials: A review of principles, design methods, and applications beyond. *IEEE Aerospace and Electronic Systems Magazine*.

[2] Saktioto, S., Siregar, F. H., Soerbakti, Y., Rini, A. S., Syamsudhuha, S., & Anita, S. (2024). Excellent integration of a multi-SRR-hexagonal DNG metamaterial into an inverted triangle top microstrip antenna for 5G technology applications at 3.5 GHz. *Przegląd Elektrotechniczny*, **100**(1), 130–133.

[3] Defrianto, D., Rizwan, Y. F., Saktioto, S., Emrinaldi, T., Sakinah, F. N., Ikhsan, M., Putri, D. K., & Soerbakti, Y. (2025). Perancangan struktur metamaterial segi empat pada frekuensi GHz untuk aplikasi antena mikro. *Prosiding Seminar Nasional Fisika Universitas Riau Ke-X (SNFUR-10)*, **10**(1), 1001.

[4] Angraini, C. Y. T., Saktioto, S., and Soerbakti, Y. (2024). Rancangan dan simulasi metamaterial struktur persegi empat sebagai aplikasi antena. *Prosiding Seminar Nasional Fisika Universitas Riau Ke-IX (SNFUR-9)*, **9**(1), 1003.

[5] Defrianto, D., Saktioto, S., Anita, S., Zahroh, S., and Soerbakti, Y. (2024). Perancangan dan simulasi antena telekomunikasi berdasarkan karakteristik metamaterial struktur lingkaran. *Prosiding Seminar Nasional Fisika Universitas Riau Ke-IX (SNFUR-9)*, **9**(1), 1002.

[6] Kim, S. H., Lee, S. Y., Zhang, Y., Park, S. J., & Gu, J. (2023). Carbon-based radar absorbing materials toward stealth technologies. *Advanced Science*, **10**(32), 2303104.

[7] Defrianto, D., Saktioto, S., Anita, S., Zahroh, S., Soerbakti, Y., and Emrinaldi, T. (2024). Analysis and modelling of the characteristics of telecommunication antennas utilising metamaterials with a circular structure. *Indonesian Physics Communication*, **21**(3), 233–238.

[8] Ogunniran, A. O., Olusesan, O. O., Salako, J. T., Edet, A. I., Oyelami, E. O., Akadiri, O. O., & Jimoh, A. A. (2025). Metamaterials and smart structures: Leveraging AI for design, optimization and adaptive engineering solutions. *Global Journal of Engineering and Technology Advances*, **24**(3), 115–139.

[9] Soerbakti, Y., Saktioto, S., Dewi, R., & Rini, A. S. (2022). A review-Integrasi lapisan tipis ZnO pada aplikasi metamaterial sebagai wujud potensi sensor ultra-sensitif dan multi-deteksi. *Seminar Nasional Fisika Universitas Riau VII (SNFUR-7)*, **7**(1), 1–9.

[10] Soerbakti, Y., Defrianto, D., Rini, A. S., & Asyana, V. (2023). Performance analysis of metamaterial antennas based on variations in combination and radius of hexagonal SRR. *Science, Technology, and Communication Journal*, **4**(1), 1–4.

[11] Soerbakti, Y., Gamal, M. D. H., Zamri, Z., Defrianto, D., & Syahputra, R. F. (2024). Negative refractive index anomaly characteristics of SRR hexagonal array metamaterials. *Science, Technology, and Communication Journal*, **4**(2), 63–68.

[12] Soerbakti, Y., Rini, A. S., Astuti, B., Anita, S., Suyanto, H., & Rati, Y. (2024). Optimization of semiconductor-based SRR metamaterials as sensors. *Journal of Physics: Conference Series*.

[13] Wang, B. X., Xu, C., Duan, G., Xu, W., & Pi, F. (2023). Review of broadband metamaterial absorbers: from principles, design strategies, and tunable properties to functional applications. *Advanced Functional Materials*, **33**(14), 2213818.

[14] Amalia, R., Saktioto, S., and Soerbakti, Y. (2024). Simulasi dan analisis sifat metamaterial struktur segitiga pada frekuensi gelombang mikro untuk aplikasi sensor medis. *Prosiding Seminar Nasional Fisika Universitas Riau Ke-IX (SNFUR-9)*, **9**(1), 1001.

[15] Li, W., Xu, M., Xu, H. X., Wang, X., & Huang, W. (2022). Metamaterial absorbers: From tunable surface to structural transformation. *Advanced Materials*, **34**(38), 2202509.

[16] Rizwan, Y. F., Saktioto, S., and Soerbakti. Y. (2024). Perancangan struktur metamaterial segi empat pada frekuensi GHz untuk aplikasi antena mikro. *Prosiding Seminar Nasional Fisika Universitas Riau Ke-IX (SNFUR-9)*, **9**(1), 1004.

[17] Saktioto, S., Soerbakti, Y., Rini, A. S., Astuti, B., Syamsudhuha, S., Anita, S., & Rati, Y. (2024). Extreme DNG metamaterial integrated by multi-SRR-square and ZnO thin film for early detection of analyte electrolyticity. *Przegląd Elektrotechniczny*, **100**.

[18] Defrianto, D., Saktioto, S., Rini, A. S., Syamsudhuha, S., Anita, S., & Soerbakti, Y. (2025). Exploration of Analyte Electrolyticity Using Multi-SRR-Hexagonal DNG Metamaterials and ZnO Thin Films. *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, **13**(2), 500–508.

[19] Defrianto, D., Kurnia, E., Saktioto, S., Emrinaldi, T., Sakinah, F. N., Ikhsan, M., & Soerbakti, Y. (2025). Electromagnetic characterization of diamond-shaped metamaterial structures using a 4×4 array at ultra-wideband frequencies. *Indonesian Physics Communication*, **22**(3).

[20] Deng, X., Zhang, D., Chen, Y., & Yang, S. (2023). Characteristic mode analysis: application to electromagnetic radiation, scattering, and coupling problems. *Chinese Journal of Electronics*, **32**(4), 663–677.

[21] Syahputra, R. F., Soerbakti, Y., Syech, R., Taer, E., & Saktioto, S. (2020). Effect of stripline number on resonant frequency of hexagonal split ring resonator metamaterial. *Journal of Aceh Physics Society*, **9**(1), 26–30.

[22] Cheraghinia, M., Shahid, A., Luchie, S., Gordebeke, G. J., Caytan, O., Fontaine, J., Van Herbruggen, B., Lemey, S., & De Poorter, E. (2024). A comprehensive overview on UWB radar: Applications, standards, signal processing techniques, datasets, radio chips, trends and future research directions. *IEEE Communications Surveys & Tutorials*.

[23] Defrianto, D., Soerbakti, Y., Syahputra, R. F., & Saktioto, S. (2020). Analisis kinerja antena berdasarkan pengaruh variasi kombinasi dan jari-jari metamaterial heksagonal struktur split ring resonator. *Prosiding Seminar Nasional Fisika Universitas Riau V (SNFUR-5)*, **5**(1), 1–4.

[24] Saktioto, S., Angraini, C. Y. T., Soerbakti, Y., Rini, A. S., Syamsudhuha, S., & Anita, S. (2025). Design and optimization of square SRR metamaterial-based microstrip antenna for wideband biomedical sensing. *Science, Technology, and Communication Journal*, **6**(1), 7–16.

[25] Saktioto, S., Soerbakti, Y., Rini, A. S., Astuti, B., & Rati, Y. (2024). Effectiveness of adding ZnO thin films to metamaterial structures as sensors. *Indonesian Physics Communication*, **21**(1), 13–27.

[26] Gamal, M. D. H., Soerbakti, Y., Zamri, Z., Syahputra, R. F., & Saktioto, S. (2020). Investigasi karakteristik anomali indeks bias negatif metamaterial array struktur split ring resonator. *Seminar Nasional Fisika Universitas Riau V (SNFUR-5)*, **5**(1), 1–4.

[27] Amalia, R., Defrianto, D., Soerbakti, Y., Asyana, V., & Abdullah, H. Y. (2024). Simulation and analysis of triangular structure metamaterial properties at microwave frequencies for medical sensor applications. *Science, Technology, and Communication Journal*, **5**(1), 15–20.

[28] Defrianto, D., Kurnia, E., Saktioto, S., Emrinaldi, T., Sakinah, F. N., Ikhsan, M., & Soerbakti, Y. (2025). Electromagnetic characterization of diamond-shaped metamaterial structures using a 4× 4 array at ultra-wideband frequencies. *Indonesian Physics Communication*, **22**(3), 213–220.

[29] Saktioto, S., Rizwan, Y. F., Soerbakti, Y., Rini, A. S., Syamsudhuha, S., & Anita, S. (2025). Design and electromagnetic simulation of rhombus-shaped split ring resonator metamaterials for telecommunication antenna applications. *Indonesian Physics Communication*, **22**(3), 179–184.

[30] Zamri, Z. & Soerbakti, Y. (2022). Determination of the most effective wifi signal intensity area in an enclosed room. *Science, Technology, and Communication Journal*, **2**(2), 69–72.