Osama K. Mohammed [1,2]
Akeel S. Tahir [1]
Wa'il A.G. Al-Tumah [1]

[1] *Department of Physics, College of Science, Basra University, Basra, IRAQ*
[2] *Technical Institute of Amara, Southern Technical University, Basra, IRAQ*

Iraqi Journal of Applied Physics
Q4 Electronic, Optical and Magnetic Materials best quartile
SJR 2022 0.19
powered by scimagojr.com

Effect of Radar Absorbing Materials on Radar Cross-Section Reduction of Complex Targets

Radar Cross Section (RCS) is a measure operated to describe the capability of a body to receive and then redirect the energy emitted by the omnipresent radar signal. (RCS) is affected by many factors, including target size, shape, material, radar frequency, and angle of incidence. Good design and use of stealth and radar wave scattering techniques are important in reducing the (RCS) and thus reducing the ability to detect the target. Radar-absorbent materials, as is evident from the name, the goal of this material is to absorb the energy of the incident wave and convert it into heat, thus reducing the amount of energy scattered toward the radar. The Radar Absorbent Material (RAM) technique was used to RCSR. The study revealed a decrease in the (RCS) when employing full and partial coatings of (RAM) on two types of isotropic and nanomaterials. The RCS is observed to be reduced by the partial coated body (hot-spot) RAM coating, and this decrease is comparable to that of a full coated. This results in a noteworthy reduction of almost 80% in the weight and volume of RAM and, consequently, in the cost of the RAM coating. Due to the difficulty of analytically methods in dealing with complex bodies, we resorted to using the High-Frequency Structure Simulator (HFSS).

Keywords: Electromagnetic scattering; Radar; Cross section; Absorbing material
Received: 22 November; **Revised:** 18 December; **Accepted:** 25 December 2023

1. Introduction

After World War II, several tools emerged as crucial components for countries' defense and security. Among these tools, radar assumed significant importance. Advancements in radar technology have led to investigations into the interplay between electromagnetic radiation and various materials [1][2].

The term radar is an acronym for Radio Detection and Ranging[3]. It is an electromagnetic system that locates targets. Radar function depends on electromagnetic waves' interactions with physical targets. This fundamental feature allows radar to detect targets and their speeds by sensing reflected waves. [4].

RCS measures the amount of backscattering power per unit solid angle (steradian) from the target to the radar[5][6], This measurement is based on target size and geometry, surface roughness, radar wavelength, radar polarization [7][8].Complex and irregular objects, there is difficulty in dealing with them analytically, so resorting to the available software that deals with electromagnetic scattering problems. Computer software is the ideal way to predict the RCS and reduce it. HFSS is a state-of-the-art electromagnetic (EM) structure solution which is using the finite element method.

Research on RCSR is crucial for various applications, particularly military ones. There are several methods used to (RCSR)[9]:Shaping technique, Radar Absorbing Material (RAM), Active cancellation and Passive cancellation. The main goal of these technologies is making it less visible to radar systems and reducing the chances of it being detected by radar[10] .

In military applications, Radar Absorbing Materials (RAMs) are used to decreasing the quantity of energy reflected from the target to the antenna of radar through an absorption process. In this technicality, dielectric and magnetic materials are arranged on the surface of the target to produce dielectric or magnetic losses. These losses are highly dependent on frequency, which determines RAM absorption performance. [11].

Alves, Port, and Mirabel conducted a 2007 study using CAD RCS to simulate (RCS) on a model aircraft (the B-2 Spirit stealth bomber). The model was coated with RAM to study the effect of aircraft shape on RCS[12].H. Oraizi, and others,2010, presented applications in double-zero (DZR) materials as (RAM).Through an inclined plane wave with arbitrary polarization, an perfect electrical conductor (PEC) plate is covered with several layers of DZR metamaterials to achieve zero reflection.[13].

A study by Che Young Kim and Geun-Sik Bae in 2013, focused on the (RCSR) for intricate naval targets such as submarines and ships. The study created a multilayer radar absorbent coating (RAC) with a 7–12 GHz frequency range, specifically in the X and C bands. [14].G. D. A. Sameer Duggal 2014 examined electric permittivity and magnetic permeability for materials to determine electromagnetic wave absorption conditions. The electric permittivity and magnetic permeability of single-layer (composite) and multilayer materials are compared to see their effects.[15].

Yuka Ishii and his team 2017 studied the features of RAM made of 3 GHz dielectrics for RCS-reducing properties. The optimal dielectric conditions from the flat-layer RAM architecture were investigated[16].

In 2018 the introduction of a brand-new (RCSR) technique by Canberk Pay and Ozlem Ozgun that involved coating objects in isotropic, physically realizable dielectric layers. The loss tangent and dielectric constant of these dielectric layers are determined by genetic optimization, which seeks to identify the ideal material parameters for the field[1].

Wei Li and colleagues, 2019, proposed a hybrid design with a magnetic absorbing material (MAM), thin thickness (d), and diffusion scattering electromagnetic band-gap (EBG) metasurface. This design reduces radar cross-section (RCS) across many frequencies[17].

A study by Shuwai Leung and others, 2021 this study presents a method for effectively reducing broadband RCS using a magnetic metasurface. The metasurface design employs a magnetic absorbing material (MAM) with high permittivity and magnetic loss[18].

Ruiz-Perez et al.,2022, Carbon-based materials such as nanotubes, graphene, reduced graphene oxide, carbon black, carbon fibers, and their composites have been employed as electromagnetic absorber materials due to their advantageous characteristics, including lightweight nature, flexibility, and desirable electric and magnetic properties.[9].

In this study, the effect of using different coating materials for the purpose of reducing RCS was studied through the use of dielectric materials with only a real dielectric constant and a real and imaginary dielectric constant, in addition to the use of isotropic and nanomaterials.

Design and Methodology

In the current work, the proposed missile was designed with the help of the HFSS simulation software, this software, which is based on the method of moments (MOM) and finite element method (FEM), is used to solve mathematical physics and engineering problems[19].

HFSS simulation software was used to design the model, the body proposed for study is a missile consists of a group of simple parts, such as a cone, a cylinder, and wings, which are connected to each other. The missile's length is 14 cm, and the height of the rear wings is 1.3 cm as shown in Fig. (1), this missile dimensions with scale 1:10 [20]. Since the target is made of conductive materials and coated with dielectric or magnetic material, this imposes the existence of two types of boundary conditions that assume that the tangential component of the electric field vanishes on the conductive surfaces while the electric and magnetic field components are continuous on the dielectric surfaces [21,22], Isotropic and nanomaterial were used in the full and partial coating processes and the axial fall of the wave.

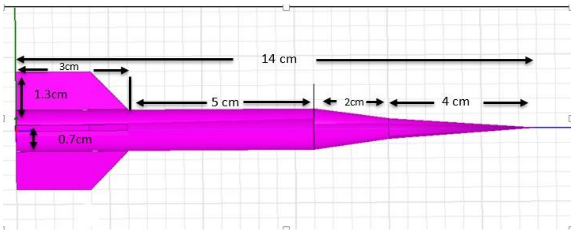


Fig. (1) The missile with its main dimensions and scale 1:10 [20]

Results and Discussion

The traditional concept of RCS, represents the ratio between the power of incident waves and total waves. Mathematically, the definition of RCS can be given as:

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \left|\frac{E_s}{E_i}\right|^2 \qquad (1)$$

where σ is RCS (m^2), variable R distance between a radiation source and a target:$E_s(V/m)$ scattering of electric field; $E_i(V/m)$ incident electric field, Quantities of an electric field can be stated using their integral representation.When R is a large value approaching infinite, the distance between the antenna and the radar satisfies the far field condition. Thus, the effect of distance on RCS can be eliminated [23,24].

The superposition of two orthogonal components usually produces the scattering waveE_θ^s ,E_φ^s, while the two components together generate the incident waveE_θ^i ,E_φ^i [25], These components for scattering and incident field are related by the scattering matrix, according to[26]:

$$\begin{bmatrix} E_\theta^s \\ E_\varphi^s \end{bmatrix} = \frac{e^{-jkr}}{r} \begin{bmatrix} S^{\theta\theta} & S^{\theta\varphi} \\ S^{\varphi\theta} & S^{\varphi\varphi} \end{bmatrix} \begin{bmatrix} E_\theta^i \\ E_\varphi^i \end{bmatrix} \qquad (2)$$

The RCS of the proposed body in the case of a conductor was calculated according to the frequency value of 15 GHz at the E-plane (φ=90) and H-plane (φ=0), incident plane wave, and axial incidence angle (θ_i=180 º), and the result was as shown in Fig. (2).

The target was coated in three layers with different thicknesses, t =1,2,1 mm. The dielectric constant for these layers consists of only a real part, which is: $\epsilon_r = 2.0, 4.0{,}6.0$, $\epsilon_r = 2.0, 4.0{,}2.0$,$\epsilon_r = 6.0, 4.0{,}2.0$, $\epsilon_r = 4.0, 2.0{,}6.0$. Comparison with the radar signature of the missile in the case of conductor, the best value for the thickness and real dielectric constant was chosen is $\epsilon_r = 2.0, 4.0{,}2.0$, which affects the RCS value of the missile, as depicted in Fig. (3).

By observing Fig. (3), we find that one and two-layer coating do not affect RCS, while in the case of coating three layers, the reduction reaches 2.9 dB. With the use of three coating layers, which are different in value in terms of the thickness of the layers and the value of the real dielectric constant, we notice that there is a decrease in the radar signature, and this is due to several Effects, including:

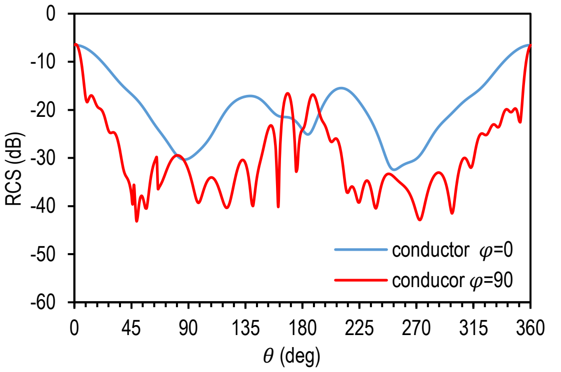


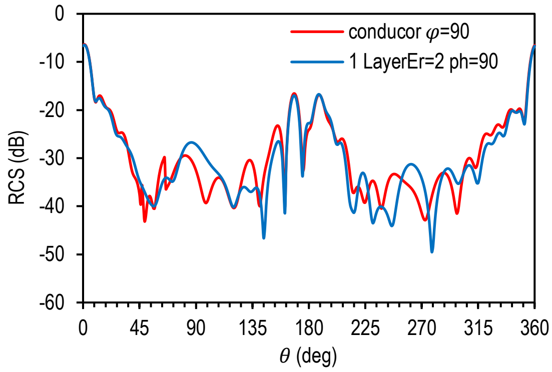
Fig. (2) Simulation RCS of the proposed body at (φ=0 and φ=90)

The radar signal is scattered when it falls on the coated surface. Since the value of the dielectric constant and the thickness of the coating are different from one layer to another, it leads to a significant dispersion of the signal, which reduces the RCS. Coating layers convert the energy of the electromagnetic wave into thermal energy. Since the layers are differentiated, refraction coefficients are different, contributing to the dispersion of energy, thus reducing the amount of signal that returns to the radar [27].

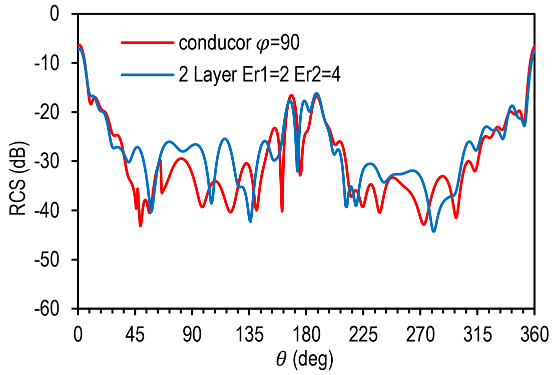
In the other test, a coating was used in three layers, with dielectric constant for each layer consisting of a real and imaginary part and the thickness of each layer d=1mm[28], Results as shown in Fig. (4), first Layer:$\epsilon_{r1} = 2.0$, $\mu_{r1} = 1.0$. Second Layer $\epsilon_{r2} = 2.0 - j2.0$, $\mu_{r2} = 2.0 - j2.0$. third Layer: $\epsilon_{r3} = 2.0$, $\mu_{r3} = 2.0$.

From Fig. (4), we find that one and two-layer coating do not affect RCS, while in the case of coating three layers, the reduction reaches 3.4 dB. In Fig. (4), we can notice a reduction in (RCS) when the dielectric constant value consists of a real part and an imaginary part. This is because the real part of the dielectric constant reduces the amount of energy that is reflected or absorbed from the material when electromagnetic waves pass through it. The imaginary part of the dielectric constant indicates the delay in the material's response to electromagnetic waves, and it also leads to a change in the cross-section. This delay means electromagnetic waves interact differently as they pass through the material. Hence, the value of RCS is lower when the dielectric constant is made up of a real part and an imaginary part than in the case of only the real part since both the real part and the imaginary part contribute to changing interaction of Matter with electromagnetic waves.

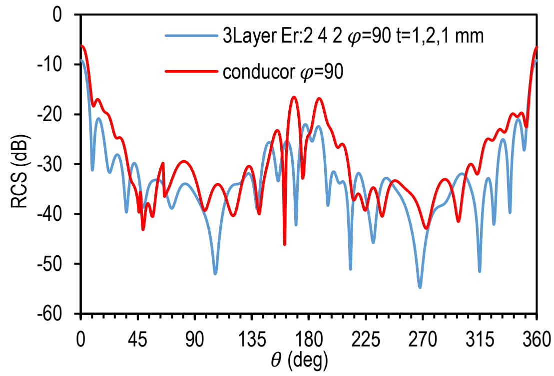
The RCS can be reduced by using full coating technique at a frequency of 15 GHz, incident angle is 180°and use of coating material to study EM scattering characteristics of a coated missile, thickness of coating is 1.2mm and dielectric parameters are [29]:



(a) One Layer



(b) Tow Layers



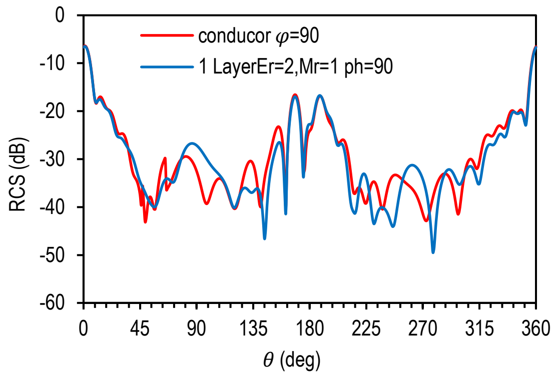
(c) Three Layers

Fig. (3) Simulation results of Bistatic RCS between the missile (conductor) and the missile (Coated) (a) One layer, (b) two layers and (c) three layers with a real Dielectric constant only at φ=90

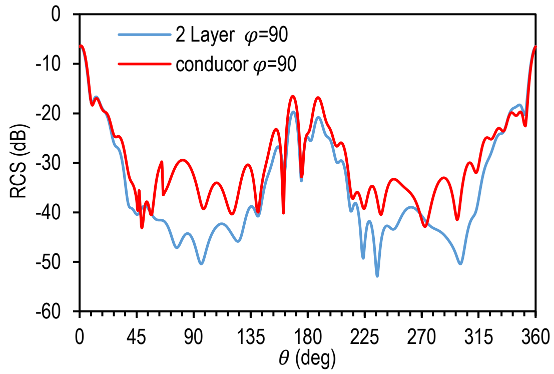
Material A: $\epsilon_r = 27.32 - j4.58$ and $\mu_r = 2.22 - j1.72$, material B: $\epsilon_r = 9 - j4.2$ and $\mu_r = 1$,These values were applied to the research model, Where A and B represents isotropic and nanomaterial, respectively.

Isotropic materials, by definition, have the same electromagnetic properties in all directions. With regard to RCS, these materials do not significantly reduce RCS value, and this material works to disperse and reflect radar waves in all directions equally.

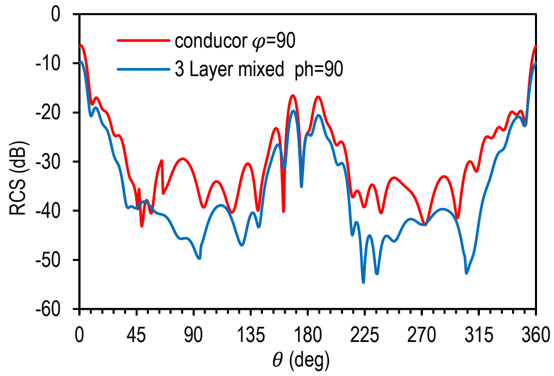
Figure (5) shows the behavior of RCS of missile when coated with Isotropic material, it shows that there is a decrease in RCS of 1.65 dB when compared to the case of the conductor.



(a) One Layer



(b) Two Layers



(c) Three Layers

Fig. (4) Comparison of Bistatic RCS between of the missile(conductor) and missile (coated) with layers :(a) one layer ,(b) two layers and (c) three layer with real and imaginary parts of dielectric constant at φ=90

Nanomaterials are commonly employed in electromagnetism due to their structure. Nanomaterials absorb waves, On the one hand, stealth aircraft, tanks, and other military equipment use Nano-absorbing materials to limit detection and destruction and improve survival [30]. Nanomaterial work to disperse the electromagnetic waves falling on them in various directions. The reason for that is the small size of these materials compared to the wavelength of the incident wave. This depends on the nature of the composition, shape, size, and electromagnetic properties of this material. This dispersion can lead to a change in the direction, polarization, and intensity of the reflected and transmitted waves.

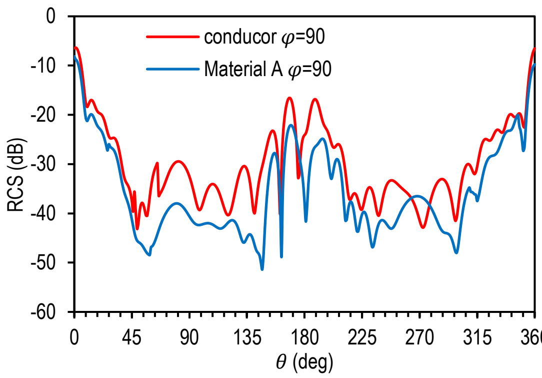


Fig. (5) Simulation Bistatic RCS between of the missile (conductor) and missile (Coated) with Isotropic materials at φ=90

Specific electromagnetic wave frequencies can be absorbed by certain nanomaterial, which cause the electromagnetic energy to be transformed into heat. Figure 5 shows the behavior of the RCS of the missile when coated with Nanomaterial, and it shows that there is a reduction in the RCS when compared to the case of the conductor.

Figure (6) shows the behavior of RCS of missile when coated with Nanomaterial, it shows that there is a decrease in RCS of 2 dB when compared to the case of the conductor.

The partial coating technique is one of the strategies aimed at reducing the RCS of targets and making them less detectable by radar systems. Instead of coating the entire target with a specific material to reduce RCS [31], partial coating is applied only to some parts of the target. The success of the partial coating technicality depends on identifying radar-sensitive parts of the target and applying partial radar coating only to these parts. This allows cost reduction and efficient use of radar materials without the need to apply them to insensitive parts. In addition, the use of partial coatings can help maintain specific functional properties of parts that are not coated.

If the partial coating is well designed and applied, this technique can be effective in improving camouflage and reducing the ability of targets to be detected by radar. However, the performance of partial coatings must be periodically tested and evaluated to ensure that their effectiveness is maintained and, if necessary, improved.

Figure (8) shows a comparison between the case of total and partial coating, which shows the convergence in RCSR, and this reflects the feasibility of using partial coating, so it may not be necessary to coat the object completely. Instead, it is enough to coat the main scattering centers (hot spots), which are the missile's cylindrical part and wing edges, which contribute to the RCS.

Comparing reduction in the value of RCS of material Isotropic with Nanomaterial, can be noted that material Nanomaterial is more reduced in Isotropic, as shown in Fig. (7).

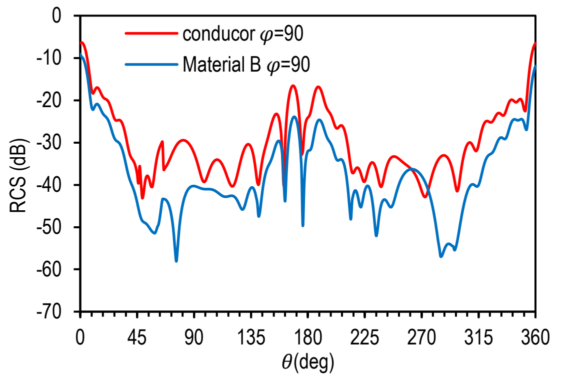


Fig. (6) Relation between the case of the conductor missile and the case of the Missile coated with Nanomaterial at *φ*=90

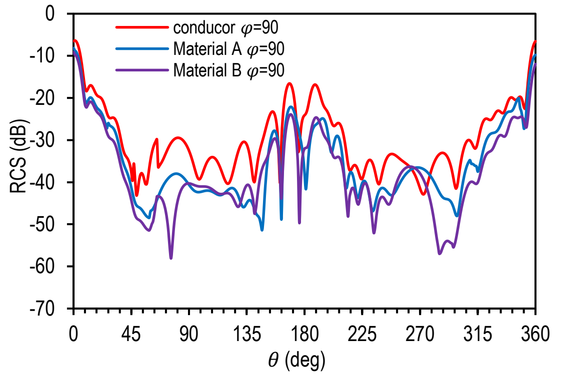


Fig. (7) Comparison between the cases of the conductor missile, coated with material (A), Missile with material (B) at *φ*=90 and frequency 15 GHz

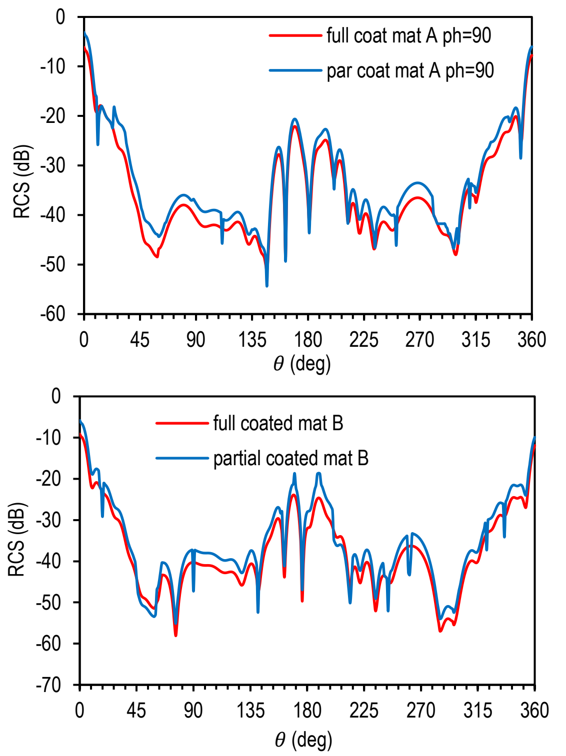


Fig. (8) Comparison between the cases of the missile full and partial coated material A and B *φ*=90

This results in a substantial reduction of approximately 80% in both the weight and volume of RAM and the associated cost of the RAM coating, reducing the cost, weight, and maintenance of the targets and not affecting the extent of military objectives. This decrease in the weight of RAM coating is invaluable to the difficulty of applying RAM coating because of the acute corner between the wing and cylinder[32].

Conclusions

In concluding remarks, the quality of materials used in coated plays an important role in reducing RCS; some materials are more effective at absorbing radar waves regardless of their thickness, while some coatings may have effective properties at greater thickness. It is not necessary to coat the entire target, but rather, the partial coating technique can be used to cover the parts that contribute significantly to RCS. This provides some benefits, the most important of which are reducing the weight of the coating, reducing maintenance, not affecting the range of the targets, and others. Coating a complete target complicates maintenance and repair. Partial coatings may require less care and be more accessible to inspect and replace. The interaction of nanomaterials is better than isotropic materials with electromagnetic waves. Specific electromagnetic wave frequencies can be absorbed by certain nanomaterial, which causes the electromagnetic energy to be transformed into heat, and this depends on their electrical and mechanical properties. The work of radar depends on sending and receiving radar waves, and at present, many studies have appeared that are interested in studying radar-absorbing materials and structures, not only for military purposes but also for protection from harmful electromagnetic waves. A higher reduction in radar signature can be obtained by increasing the thickness or the number of coating layers, but this leads to an increase in the weight of the targets.

References

[1] C. Pay and O. Ozgun, “A Radar Cross Section Reduction Method Using the Concept of Coordinate Transformation and Isotropic Dielectric Layers”, *18th Mediterr. Microw. Symp.*, October 2018, 101-103.
[2] A.M. Ahmed, I.H. Ali and H.R. Hatem, “Bi and Mono Static Radar Cross Section Computation for Various Target’s Materials”, *Int. J. Eng. Technol.*, 8 (2019) 513-516.
[3] J.F. Shaeffer, M.T. Tuley and E.F. Knott, “Radar Cross Section Reduction”, *Radar Cross Sect.*, 9(1) (2013) 269-295.
[4] K. Ramya, “Radar Absorbing Material (RAM)”, *Appl. Mech. Mater.*, 390 (2013) 450-453.
[5] H.K. Ali, “Study of the Effect of RCS on Radar Detection”, *Eur. Sci. J.*, 13(15) (2017) 148.
[6] N. Swathi et al., “RCS Computation of Shapes Obtained by Cascading Simple Objects Using PO Method and Results Obtained Using Matlab Simulation Software”, *Int. J. Electron. Commun. Technol.*, 4(2) (2013) 11-16.

[7] M.A.S. Miacci and M.C., "Basics on Radar Cross Section Reduction Measurements of Simple and Complex Targets Using Microwave Absorbers", *Appl. Meas. Syst.*, 24 February (2012) 351-375.
[8] V.D.C.J.M.G. Torres, "Analysis of radar cross section assessment methods and parameters affecting it for surface ships", *Cienc. y Tecnol. buques*, 6(11) (2012) 91-106.
[9] F. Ruiz-Perez et al., "Carbon-based radar absorbing materials: A critical review", *J. Sci. Adv. Mater. Dev.*, 7(3) (2022) 100454.
[10] I. Nicolaescu, "Radar absorbing materials used for target camouflage", *J. Optoelectron. Adv. Mater.*, 8(1) (2006) 333-338.
[11] G.S. Bae and C.Y. Kim, "Design of Multi-Layer Radar Absorbing Coating and Transparent Shielding Film for RCS Reduction of Complex Targets", *Appl. Mech. Mater.*, 799/800 (2015) 1370-1378.
[12] M.A. Alves, R.J. Port and M.C. Rezende, "Simulations of the radar cross section of a stealth aircraft", *SBMO/IEEE MTT-S Int. Microw. Optoelectron. Conf. Proc.* (2017) 409-412.
[13] H. Oraizi, A. Abdolali and N. Vaseghi, "Application of double zero metamaterials as radar absorbing materials for the reduction of radar cross section", *Prog. Electromagn. Res.*, 101 (2010) 323-337.
[14] G.-S. Bae and C.Y. Kim, "Broadband multilayer radar absorbing coating for RCS reduction", *Microw. Opt. Technol. Lett.*, 56(8) (2014) 1907-1910.
[15] G.D.A. Sameer Duggal, "Review on Effect of Electric Permittivity and Magnetic Permeability over Microwave Absorbing Materials at Low Frequencies", *Int. J. Eng. Adv. Technol.*, 3(5) (2014) 12-19.
[16] Y. Ishii et al., "A study for radar absorbent material composed of dielectric materials considering frequency dependency", in *2017 Int. Symp. on Antennas Propag. (ISAP)*, IEEE, October 2017, pp. 1-2.
[17] W. Li et al., "Broadband radar cross section reduction by in-plane integration of scattering metasurfaces and magnetic absorbing materials", *Results in Phys.*, 12 (2019) 1964-1970.
[18] S. Leung et al., "Broadband radar cross section reduction by an absorptive metasurface based on a magnetic absorbing material", *Opt. Exp.*, 29(21) (2021) 12.
[19] W.A. Godaymi Al-Tumah, R.M. Shaaban and A. Tahir, "Design, simulation and measurement of triple band annular ring microstrip antenna based on shape of crescent moon", *AEU - Int. J. Electron. Commun.*, 117 (2020) 1-23.
[20] X. Deng et al., "A Novel PE/FDTD Hybrid Model for Predicting Echo Signals of Radar Targets in Large-Scale Complex Environments", *IEEE Access*, 8 (2020) 28450-28461.
[21] M. Alnawars, W.A. Godaymi Al-Tumah and R. Malallah, "Design of Wraparound Microstrip Antenna using the Method of Moment", *Open J. Sci. Technol.*, 3(3) (2020) 266-273.
[22] W.A. Godaymi, A.-K.A.A. Mohammed and Z.A. Ahmed, "Determination of Surface Currents on Circular Microstrip Antennas", *J. Electromagn. Eng. Sci.*, 12(4) (2012) 260-270.
[23] L. Niu et al., "ARCS: Active Radar Cross Section for Multi-Radiator Problems in Complex EM Environments", *Sensors*, 20(12) (2020) 3371.
[24] El.M. Hamham, A. Zugaria and A. Benali, "Calculating Radar Cross Section of Lossy Targets Using the Surface Impedance Approach", *Prog. Electromagn. Res. M,* 55 (2017) 13-24.
[25] A.S. Tahir, A.H. Abood and W.A. Godaymi, "Scattering From Dielectrically Coated Bodies Of Revolution With Attached Wires", *Misan J. Acad. Stud.*, (2016) 243.
[26] A.H.A. Zaki, A. Ahmed, R.A. Al-Assdi, "Studying the effect of conductiong bodies of revolution (BoR) shape on computing radar cross section (RCS)", *J. Missan Res.*, 6(11) (2009) 43-65.
[27] A. Kumar and S. Singh, "Development of Coatings for Radar Absorbing Materials at X-band", *IOP Conf. Ser. Mater. Sci. Eng.*, 330 (2018) 012006.
[28] L. Lei, J. Hu and H.-Q. Hu, "Solving Scattering from Conducting Body Coated by Thin-Layer Material by Hybrid Shell Vector Element with Boundary Integral Method", *Int. J. Antennas Propag.*, 2012(1) (2012) 1-7.
[29] C. Dong, L. Guo and X. Meng, "Application of CUDA-Accelerated GO/PO Method in Calculation of Electromagnetic Scattering From Coated Targets", *IEEE Access*, 8 (2020) 35420-35428.
[30] J. Chen and C. Mou, "The HIE-FDTD Method for Simulating Dispersion Media Represented by Drude, Debye, and Lorentz Models", *Nanomater.*, 13(7) (2023) 1180.
[31] H. Zeng et al., "Fast coating analysis and modeling for RCS reduction of aircraft", *Chinese J. Aeronaut.*, 32(6) (2019) 1481-1487.
[32] J.B.A. Upendra Raju, "A Novel Method for RCS Reduction of a Complex Shaped Aircraft Using Partial RAM Coating", 2(2) (2012) 52-56.

