Review of Computer Engineering Research
2023 Vol. 10, No. 1, pp. 1-15.
ISSN(e): 2410-9142
ISSN(p): 2412-4281
DOI: 10.18488/76.v10i1.3308

Increasing the radar cross section using phase array antenna in the body structure of miniature air-launched decoy platforms

Ozge Bayri Otenkaya[1+]
Ahmet Gungor Pakfiliz[2]

[1,2]*Department of Electrical & Electronics Engineering, Baskent University, Ankara, Turkey.*
[1]*Email: ozge.bayri@hotmail.com*
[2]*Email: apakfiliz@baskent.edu.tr*

(+ Corresponding author)

Article History
Received: 14 December 2022
Revised: 31 January 2023
Accepted: 16 February 2023
Published: 2 March 2023

Keywords
Air-launched decoy platform
Conformal antenna
Early warning radar
Fighter plane
Microstrip antenna
Phase array antenna
Radar cross section.

ABSTRACT

Decoys have a crucial role in the electronic countermeasure and deception concepts, and many works and developments have been realized over the past few decades. The most impressive one is the miniature air-launched decoy (MALD)s. They are used to give the impression of an attack in enemy airspace by imitating the fighters' radar signatures and flight profiles. However, they resemble the emission of the fighters; their radar detection probabilities are lower than fighters due to their low radar cross-section (RCS)s. This situation results suspiciously and provides a basis for discriminating a MALD from a fighter. Thus, the emission and the MALD system's RCS must resemble a fighter. This study presents a method for increasing the RCS of MALD systems by using phased array antennas. So, a different approach is developed for covering the surface of the MALD platform with a phased array antenna with using ANSYS High Frequency Structural Simulator (HFSS) program. The phased array antenna structure analysis for different radiating elements has been conducted on the ANSYS HFSS program. A microstrip antenna, a dipole antenna, and bow tie antenna structures were analyzed, and the results were compared. The antenna structure with the best results was decided and applied to the missile. The increased MALD system's RCS has been compared with the fighter's RCS, and satisfactory results have been obtained.

Contribution/Originality: This study focuses on imitating the radar cross section of warplanes by deceiving enemy forces and increasing radar cross section. Compared with the proven methods at the preprocessing stage, most studies aim to reduce the radar cross section. But, in this study, reflective antennas have been studied to increase the radar cross section.

1. INTRODUCTION

Many developments have occurred in air battle systems to achieve air superiority to mislead and trap enemy forces. Airborne Miniature Deception (MALD) concept is an important example that developed in this context for the success of aerial warfare. These platforms ensure the operation's success by showing the warplanes' position in the air at a different point than it is. They are also deployable in real-time via an onboard data link. They are capable of low-altitude penetration from enemy territory, which can help to enter the target area before they can be used in electronic warfare. Upon entering the target area, the confidentiality of the air defense aircraft will be protected, and it will help to destroy the enemy air defense systems with the deception method.

When warplanes enter the enemy airspace, it must be difficult for the enemy forces to detect the warplane for the operation to be successful. It will be easier to mislead the enemy if the airborne deception platforms show the position of the warplanes in a different place. The radar cross section must be high for the enemy to see the air-launched decoy platforms instead of the warplanes. When the radar cross section of these platforms is increased, the enemy will not be able to see the warplanes in operation, instead they will see the air-launched decoy platforms and have an incorrect location information.

Radar cross section (RCS) can be defined as the electromagnetic energy captured by any object and re-emitted in the same direction. The RCS of a target is the equivalent area seen by radar. RCS has become essential for sending deceptive signals to enemy forces in miniature air-launched decoy platforms.

In the past studies, radar cross-sectional area analyzes of warplanes were made using different methods. Most of these studies were carried out to reduce the radar cross section and to reduce the visibility of warplanes so that the aircraft could not be detected by the enemy.

In previous studies, the radar signature has been tried to be reduced in wideband using a microstrip slot antenna array. Using parasitic elements or removing some resistive elements increases the gain. However, it was emphasized that the cross section of the monostatic radar also varies due to the onset of grating lobes [1]. One of the methods that increase or decrease the radar cross-sectional area is the shape and material type of the material. The material used on fighter aircraft and the curves of the aircraft affect the performance of the radar cross section [2, 3]. Another method used to analyze the radar cross-section is the physical optics method. To use this method, analyzes are performed using cylinder and conical objects that represent the body of the missile. When this method is used on stealth aircraft, a decrease in the radar cross-sectional area is detected and the visibility of stealth aircraft is reduced [4]. Radar cross section analyzes are also performed with the scaled model of the targeted model. Since the scale is getting smaller, analysis close to reality can be made by increasing the frequency. A method developed for bistatic RCS measurements via Terahertz (THz) waves. In one study, the F-16 warplane was scaled down and analyzed. By scaling wavelengths and models to real-scale platforms, detailed comparisons can be made with RCS of life-size aircraft at standard Megahertz (MHz)/ Gigahertz (GHz) frequencies [5]. When considering the studies, analyzes were made to reduce the RCS area. However, the radar cross section should be high to increase the MALD platform's deceptive effect against enemy forces. Increasing the RCS of MALD platforms on aircraft operating in the operational area in a specific direction is an active protection method against radar-guided threats. These decoy missiles can deceive, confuse, or even temporarily blind various radar and air defense points.

In addition to electronic suppression methods for air defense systems, MALD publishes friendly aircraft profiles and radar signals by copying them. Radars are used in civil and military fields. Civilian uses include air traffic control and flight management, maritime and land traffic management systems, weather radar, search and rescue, security, and speed control of cars. If we look at the military usage areas, surveillance, observation, target classification, early warning systems, missile defense, air attack warning, guidance systems, positioning in operations, simulation, and modeling tasks. As the RCS level increases, the MALD platforms' deceptive effect on the enemy forces will increase. To increase the level of the RCS, a study will be made on a structure consisting of phased array antennas.

Phased array antennas are becoming more and more critical for Electronic Warfare applications. Phased array antennas on radars can instantly switch from one target to another so that more than one target can be tracked effectively. Phased array antennas are an antenna group where each radiator can be fed with different phase angles. This group creates an electronically controllable antenna beam. As a result, all antenna radiation can be electronically deflected. Electronic routing is much more flexible and requires less maintenance than mechanical routing of the antenna. Any antenna structure can be used as a radiator in an antenna field. The most prominent feature of a Phased array antenna is the phase shift amount of each radiator can be adjusted, and as a result, the main direction of the radiation beam can be changed. Many radiators are used to obtain horizontal and vertical radiation beams in an antenna plane. Each element of the phase-shifted array antennas is fed with appropriate phase values, allowing the antenna to scan at very high speeds in space without being subject to mechanical restrictions. The analysis of the phased array antenna structure planned to be used on the MALD body will be made on the ANSYS HFSS program, and the results will be the subject of this thesis study.

2. RADAR CROSS SECTION OF MINIATURE AIR-LAUNCHED DECOY PLATFORM

The RCS of a target contains information that is significant for scientific research and target recognition. While current radar technology can be used for a target's distance and speed, it is challenging to target size. RCS is defined by the electromagnetic wave reflected from a target and is related to the geometric complexity of the target. RCS (σ) is a combination of geometric cross-section (S), reflection (R), and reflection wave direction (D). RCS is a measure of a target's ability to reflect radar signals back to a radar receiver, a measure of backscatter performance.

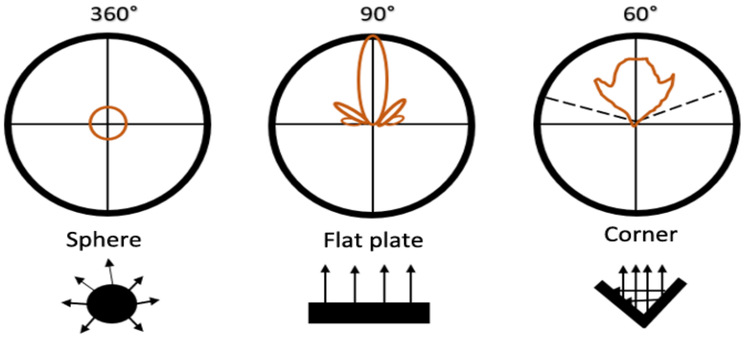


Figure 1. RCS reflections and beams in different objects.

In Figure 1 shows that the sphere is essentially the same in all directions. Flat plates have little RCS unless they are aimed directly at the radar. A corner reflector's RCS is almost the same as a flat plate's, but at a larger angle. Many targets such as ships and planes often have reflective corners. An aircraft is complex because it has many reflective elements and shapes. The RCS is important to aircraft because the radar is the leading equipment to detect and track them. Radar cross section of an object,

$$\sigma = \frac{P_R}{S_I} = \frac{\text{Power radiated from the target [W]}}{\text{Incoming power density received by the target[W/m}^2]} \ (\text{m}^2) \tag{1}$$

Where P_R is radiated power, S_I is incoming power and
Unit power density and total power relationship,

$$P_R = 4\pi r^2 S_I \tag{2}$$

$$\sigma = \frac{P_R}{S_I} = 4\pi r^2 \frac{S_R}{S_I} \tag{3}$$

Where S_R is radiated power. Finally radar cross section expression calculated in m^2 according to Formula 1. In electromagnetic analysis this is commonly written as,

$$\sigma[m^2] = \frac{P_R}{S_I} = \lim_{r\to\infty} 4\pi r^2 \frac{S_R}{S_I} = \lim_{r\to\infty} 4\pi r^2 \frac{(E_s{}^2)}{(E_g{}^2)} \tag{4}$$

The radar cross section is frequency and angle (direction) dependent.

$$\sigma = (\theta, \emptyset, \omega) \tag{5}$$

Radar cross-sectional area is usually given in dBsm (= dB square meter) with reference to $1m^2$.

$$\sigma[dBsm] = 10 \log\left(\frac{\sigma[m^2]}{1\, m^2}\right) \rightarrow \ \sigma[m^2] = \ 10^{\sigma[dBsm]/10} \tag{6}$$

2.1. Miniature Air-Launched Decoy Platform

MALD is a small, low-cost, air-launched vehicle that mimics how fighter, attack, and bomber aircraft appear to radar operators of enemies. Combat commanders use MALD-equipped units to deceive, distract, and saturate enemy radar operators and integrated air defense systems to improve access to the battlefield for airborne assault forces.

These units are designed to deceive enemy radars and air defense systems, allowing an airborne attack force to fulfill its mission [6].

The MALD concept has grown and capability over the years. Today MALD has a range of approximately 500 miles and a flight time of one hour. The advanced MALD platform will enable real-time re-commissioning and low-altitude penetration from enemy territory via an onboard data link [7].

2.2. MALD Analysis Results

In this study, the step model of the MALD platform was created and transferred to the ANSYS HFSS program before the antenna and RCS analyzes were performed. The fuselage materials, wings, and tail sections were chosen as aluminum. The view of the MALD platform from the side and nose of the ANSYS HFSS program is shown in Figure 2.

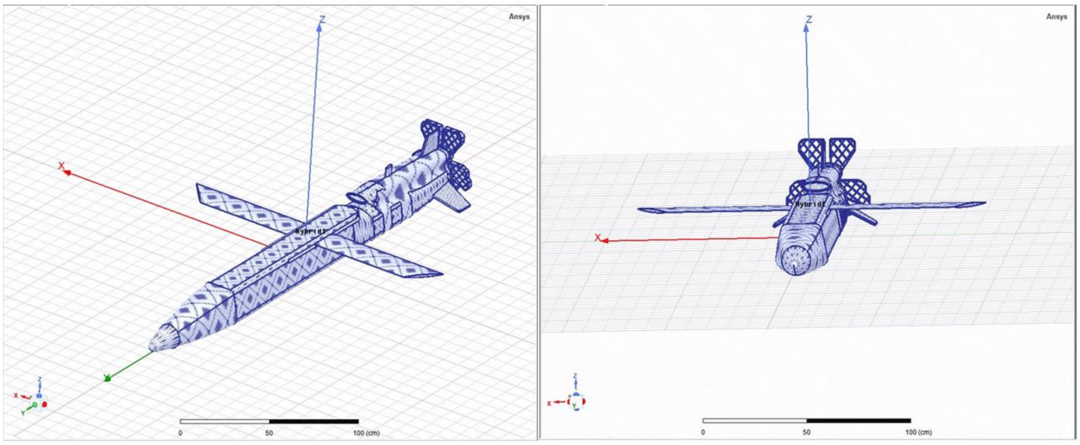


Figure 2. MALD platform CAD model pictures.

The analysis was performed linearly between 1 GHz and 4 GHz in 0.1 GHz steps. The Finite Element Boundary Integral (FE-BI) was used as the analysis solver. FE-BI is a highly accurate solution for radiation and scattering problems and compatibility to minimize solution volume. This method consists of the combination of Integral Equation (IE), which provides solutions to external surfaces, and Finite Element Method (FEM), which provides solutions to the interior. The solution generates 300,000 meshes on the platform, and automatic adaptive meshing provides an automatic, accurate, and efficient solution, eliminating the need for manual meshing know-how. The meshing algorithm adaptively refines the mesh over the geometry. It iteratively adds additive mesh elements in areas where a finer mesh is needed, resulting in an accurate and efficient mesh distribution. To realize the problem in the computer environment and solve it numerically, it is necessary to reduce it to a finite number of unknowns. In this direction, the first step is to create a network structure by dividing the physical definition range into smaller sub-areas and treating it with a finite number of elements. It is not possible to simulate any solution interface without creating a network structure.

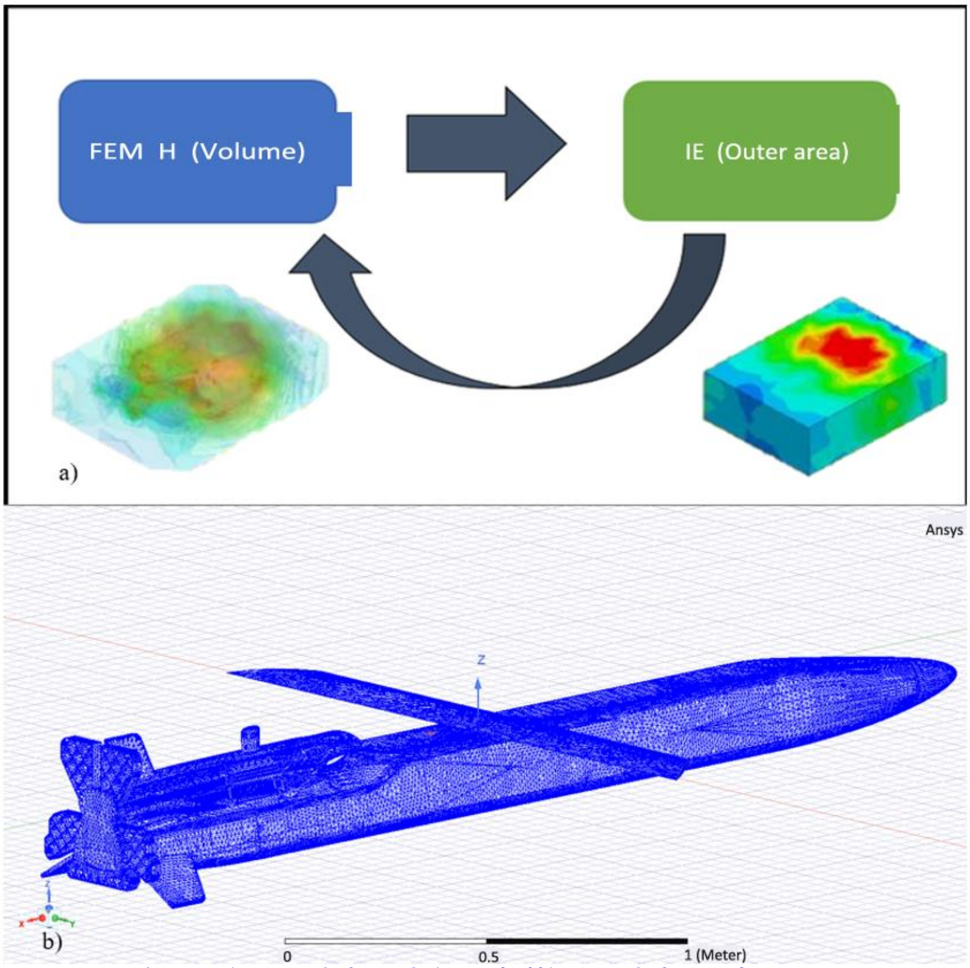


Figure 3. a) MALD platform solution method b)MALD platform mesh structure.

The mesh structure resulting from the analysis is shown in Figure 3.

Maximum Delta S determined default value 0.02 and this value reports the worst-case violation as the formula,

$$\text{Max}(\Delta S) = \text{Max}\,[S]_N - [S]_{N-1} \quad (7)$$

At the same scan intervals, the range of the phi angle is adjusted to 0 -360 degrees, the theta angle is 90 degrees in Figure 4 and the aircraft's radar cross-section results are observed.

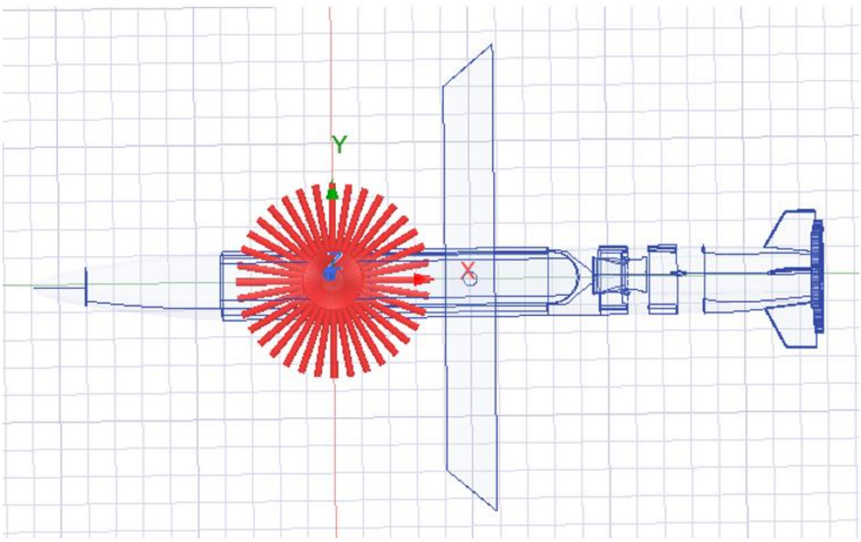


Figure 4. MALD platform phi and theta angles.

MALD Platform's length is 2.38 m (7 ft 9.8 in), diameter is 15.2 cm (6 in) and wingspan is 0.65 m (2 ft 1.4 in). Radar frequency is between 1-4 GHz. If 2 Ghz selected, wavelength calculation,

$$\boldsymbol{\lambda} = \frac{c}{f} = \frac{3x10^8}{2x10^9} = 0.15 \text{ m} \tag{8}$$

Radar cross section and main lobe calculation formulas for flat plate,

$$\boldsymbol{\sigma_1} = \frac{4\pi A^2}{\lambda^2}\ [\boldsymbol{m^2}] \tag{9}$$

From $\boldsymbol{m^2}$ to dB,

$$\text{dB} = 10\log\frac{\sigma_1}{I_0} \quad , \boldsymbol{I_0 = 1x\ 10^{-12}\ W/m^2} \tag{10}$$

One can estimate the width of the main lobe from,

$$\frac{\sigma}{\sigma_0} = \left(\frac{\sin(ka\ \sin\theta)}{ka\ \sin\theta}^{\,2} \right) \tag{11}$$

Zero occurs when ka sinθ=π.

$$\theta = \arcsin\,(\pi\ /ka) \tag{12}$$

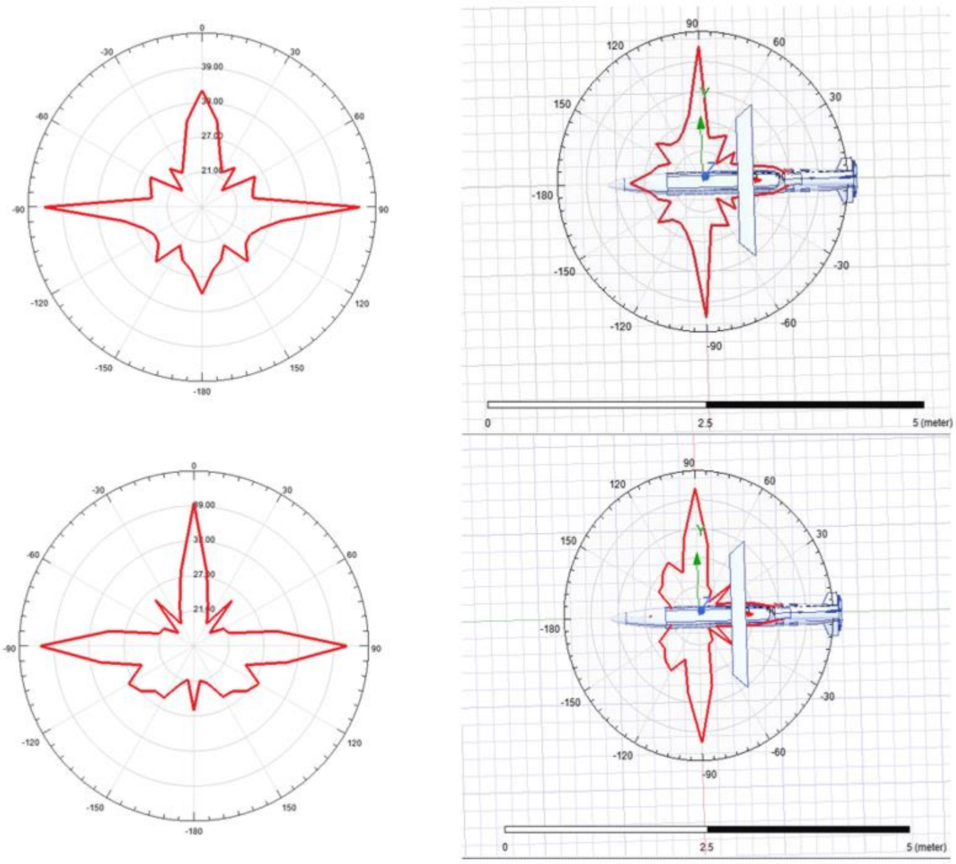
Radar cross section and main lobe calculation formulas for leading edge of starboard canard,

$$\sigma_1 = \frac{9}{4}\pi A^2 \tag{13}$$

Radar cross section and main lobe calculation formulas for fuselage and trailing edge of port wing,

$$\sigma = \pi\rho_1\rho_2\ [m^2] \tag{14}$$

Analysis results for 1GHz, 2GHz, 3GHz and 4 GHz are given in the Figure 5.



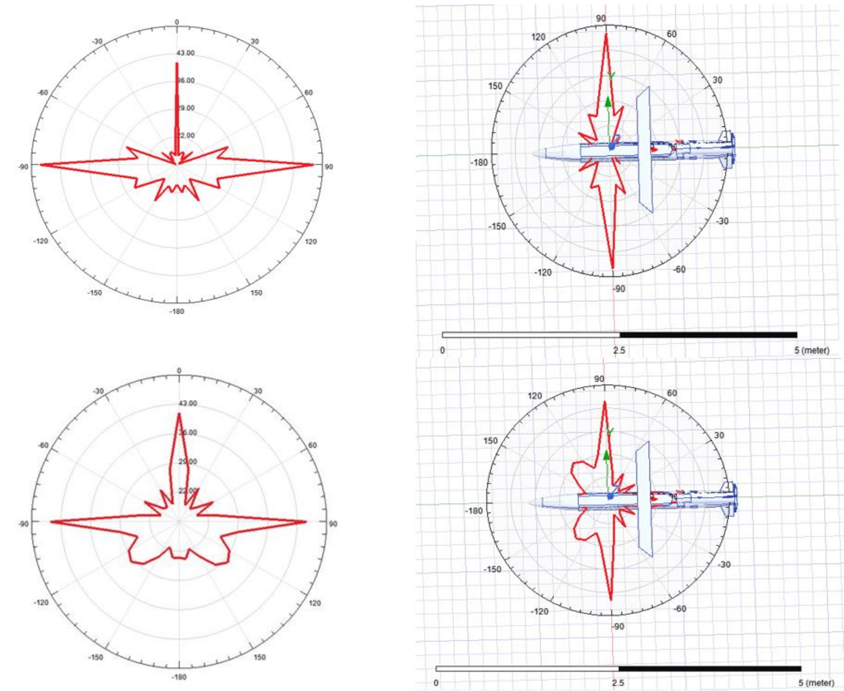


Figure 5. RCS results of MALD platform for 1-4 GHz.

According to these results, the miniature air-launched platform's wings have high RCS values due to its shape, and the nose has low RCS values because of the sphere structure. In the Table 1, the RCS increases in high frequencies and decreases in low frequencies.

Table 1. Phi degree versus monostatic radar cross section values for frequency.

Phi (Deg)	1 Gz (dBm)	2 Ghz(dBm)	3 Ghz (dBm)	4 Ghz(dBm)
0	31.85	26.78	30.14	38.75
90	42.14	42.23	27.93	37.82
180	29.46	29.26	32.88	32.53
270	41.86	44.51	33.24	37.29
360	31.85	26.78	30.14	38.75

3. DESIGN A SURFACE MOUNTING ANTENNA

This section discusses 3 different antennas and their radar cross section effects on missile body. The radar cross section effect of each antenna is at different levels. The effect levels of these antennas on the radar cross section will be checked and the most suitable antenna model will be applied to the missile body and analyzed.

3.1. Microstrip Antennas

Microstrip patch antennas are well known for their performance, robust design, manufacturing, and widespread use. Due to its simple design, lightweight, applicability, and low cost, it is used in many fields, from military vehicles to space travel. A microstrip antenna consists of a dielectric substrate sandwiched between her two conductive planes, an antenna plane, and a ground plane. This is a simplified design of an edge-fed rectangular microstrip patch antenna.

A microstrip line feed attaches a conductive strip directly to the edge of a microstrip patch. This strip is narrower than a patch, and this type of feed arrangement has the advantage that the feed can be etched on the same substrate structure. The purpose of the internal cut of the patch is to match the power line impedance to the patch that requires an additional matching element.

Coaxial or probe feeding is the primary technique used to feed microstrip patch antennas. The coaxial connector's inner conductor runs along the dielectric and is soldered to the radiating patch, but the outer conductor connects to the ground plane [8].

The main advantage of this type of feeder is that the feed can be placed anywhere in the patch to match the input impedance. This supply method is easy to manufacture and has low interference emissions. However, their main drawbacks are their low bandwidth and the need to drill holes in the board, making them difficult to model. Since the connector protrudes above the ground plane, it will not be perfectly planar for thick boards. Also, longer probe lengths for thicker boards make the input impedance more inductive, creating matching problems. In this study, coaxial-type feeding is not used because it is difficult to model and unsuitable for the MALD platform since it is necessary to drill holes in the substrate. In the proposed model, microstrip antennas were found suitable for analysis in terms of feasibility, cost, and effective results. Microstrip antenna calculation formula,

$$\text{Width}=\frac{c}{(2f_0)\sqrt{\frac{\varepsilon_R+1}{2}}};\ \varepsilon_{eff} = \frac{\varepsilon_R+1}{2}+\frac{\varepsilon_R-1}{2}\left(\frac{1}{\sqrt{1+12(\frac{h}{W})}}\right) \tag{15}$$

$$\text{Length}=\frac{c}{(2f_0)\sqrt{\varepsilon_{eff}}}-0.824\text{h}\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{16}$$

3.2. Microstrip Antenna Analysis

2 GHz microstrip antenna was selected to analyze of missile. Specifications of this antenna; dielectric constant ($\boldsymbol{\varepsilon_R}$) is 2.2 because of duroid material, dielectric height(h) is 1.5 mm and the resonant frequency is 2 GHz. According to Formula 2 and 3, the microstrip antenna patch length is 49.85 mm, and the patch width is 59.3 mm. Also, the feed width is 4.93 mm, and the feed length is 45 mm.

The radar cross section formula of antenna,

$$\sigma = [\sqrt{\sigma_s} + \sqrt{\sigma_e}\exp 1]^2 \tag{17}$$

σ_s is radar cross section of structural scattering term and σ_e is the effective echo area of antenna. The value for σ_e is, for certain specific conditions,

$$\sigma_e = \frac{\lambda^2}{4\pi}G^2 \tag{18}$$

Where G is antenna gain at λ. As an estimate one can use,

$$\sigma = \frac{\lambda^2 G^2}{\pi} \tag{19}$$

for antenna RCS. Antenna gain calculation formula,

$$G_{dB}= 10\ log_{10}\ (4\pi\eta A/\lambda^2) \tag{20}$$

G_{dB} is the antenna gain, η is the efficiency, A is the physical aperture area and λ is the wavelength of the signal. If the aperture gains 5, the wavelength is 0.5 m, and the efficiency is 80%. This antenna radar cross section,

$$\sigma = \frac{\lambda^2 G^2}{\pi}= \frac{(0.5)^2 25}{3.14} = 2\ \text{dB}m^2 \tag{21}$$

A conformal microstrip antenna array is the preferred choice among other systems due to its lightweight, low profile, low cost, integrability with microwave circuits, and simple fabrication. Developing efficient design techniques for microstrip antennas, which are calculated using the latest technology and supported by electromagnetic tools, and programs that reduce the computation time with high accuracy results have been developed [9].

Firstly, the cylinder object, like the missile's body, has been created in the Ansys HFSS program. Antenna analyses have been examined in this cylinder after the best antenna solution is applied to the MALD platform.

Early Warning Radar (EWR) intelligence is a critical support resource for commanders and agencies in joint operations because of its ability to provide real-time information about the situation in the airspace of operations, especially in assessing the threat posed by enemy aircraft in the airspace of operations [10, 11]. The frequency of Early warning radars generally between 1-4 GHz. Also, the frequency L-band(1GHz-2GHz) and S-band(2GHz-4GHz) from 1 to 4 GHz, are widely used by many types of radars to identify and tracking targets such as aircrafts, missiles, and other objects in a certain site. So, missiles were analyzed between 1GHz - 4 GHz frequency.

In Figure 6, analyses performed for 1-4 GHz. In the left side, cylinder is seen without antenna, in the right side, cylinder is seen with antenna.

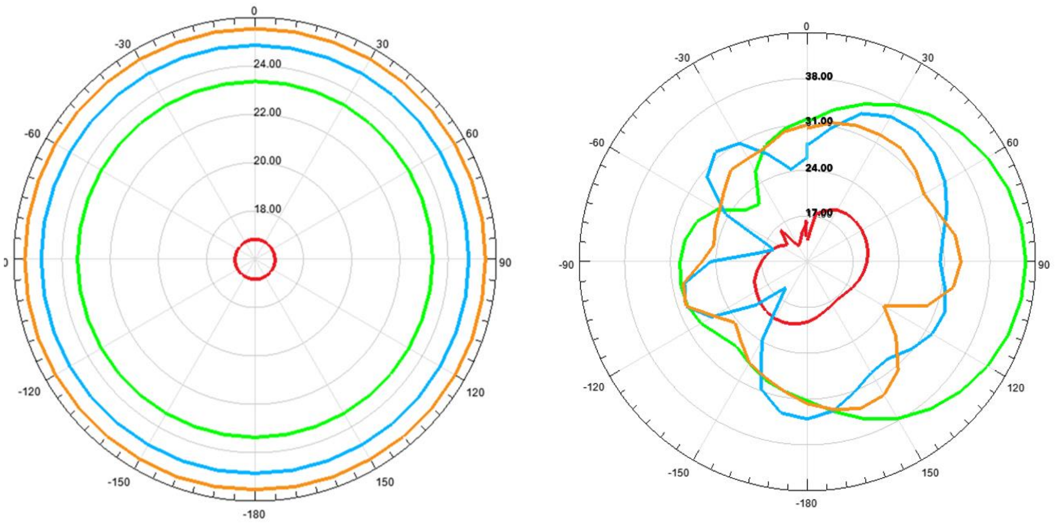


Figure 6. Microstrip antenna RCS results.

According to results, beam of radar direction changed to the antenna part. Also, rate of radar cross section increased average 20 dBm. After that, four microstrip patch phase array antenna covered to cylinder in Figure 7.

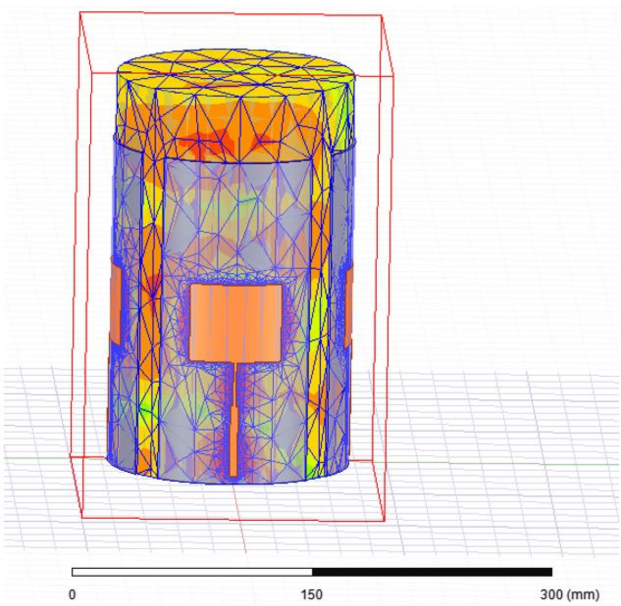


Figure 7. A cylinder covered with 4 microstrip antennas.

When the number of antenna increased to 4, the reflectivity level became evenly distributed in all directions, and the RCS level for frequencies 1,2,3 and 4 GHz showed in Figure 8. The maximum RCS is seen at 2 GHz.

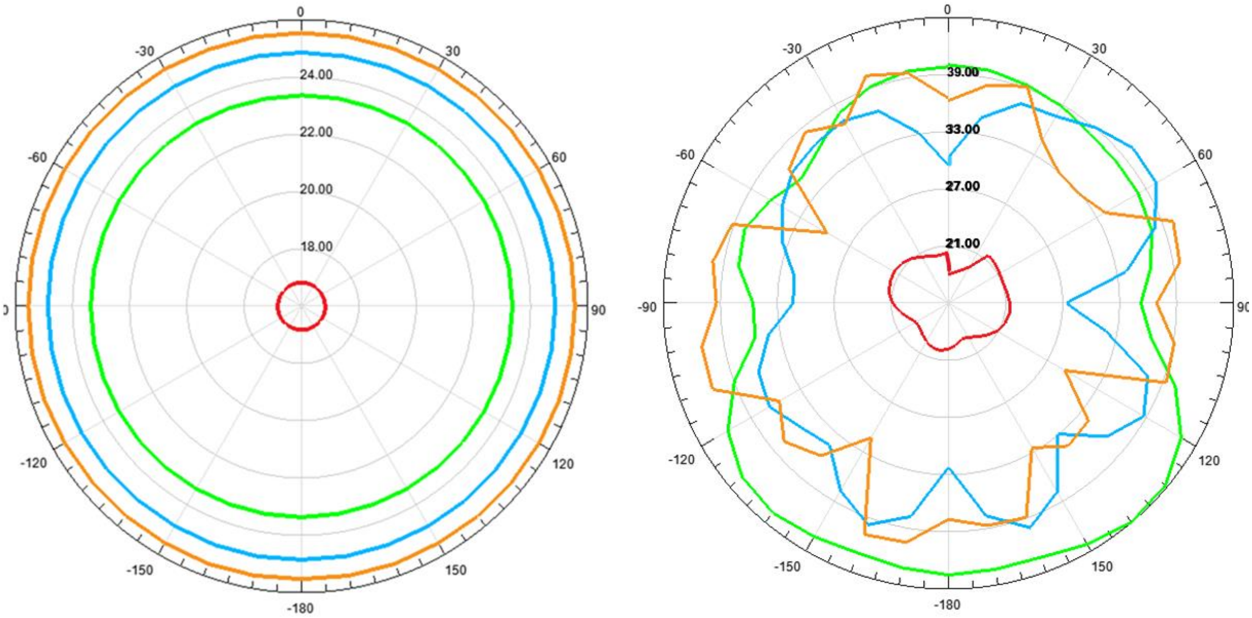


Figure 8. 4 number microstrip antennas RCS results.

3.3. Printed Dipole Analysis

Printed dipole antennas are preferred in wideband applications due to their advantages such as low profile, small size, lightweight, low cost, ease of integration, and ease of manufacture [12]. The printed dipole antenna's length is 6.09 cm, width 0.15 cm, and feed gap width 0.15 cm. Also, the substrate height is 0.1575 cm, substrate dimension (X) 9.1 cm, and substrate dimension (Y) 12.2 cm. A printed dipole antenna is covered in a cylinder and analyzed for 1,2,3, and 4 GHz. In 2 GHz frequency, maximum 43 dBm was detected in Figure 9.

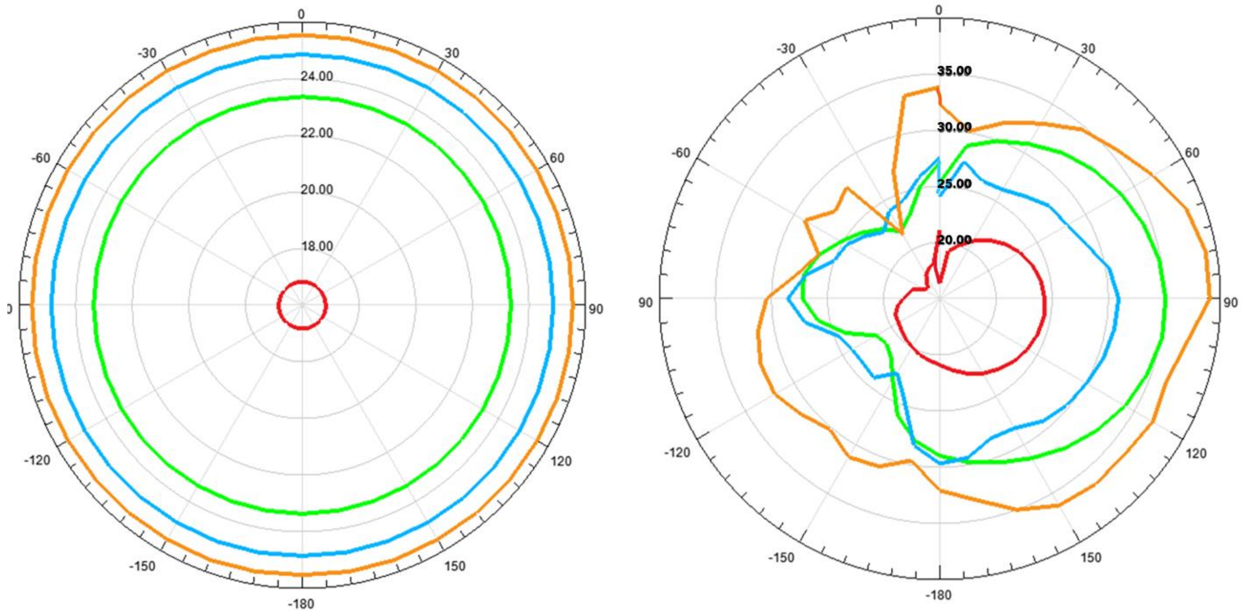


Figure 9. Printed dipole antenna RCS results.

The radar cross section formula of antenna for the maximum gain=2.53,

$$\sigma = \frac{\lambda^2 G^2}{\pi} = \frac{(0.5)^2 6.4}{3,14} = 0.5 \text{ dB}m^2 \quad (22)$$

3.4. Surface Bowtie Antenna Analysis

A bowtie antenna consists of an antenna placed at a specific angle between two pieces of metal. The antenna feed where the positive and negative terminals connect to the antenna is in the center of the antenna. These antenna properties are inexpensive and easy to build. Here, the antenna is infinitely long in both directions, so wavelength does not enter the equation. As a result, this antenna theoretically has infinite bandwidth, since it looks the same at all wavelengths. A bow tie antenna uses triangular elements instead of a straight rod as the antenna element. The name derives from the triangular elements protruding on either side of the antenna, resembling a bow tie.

The "wings" of the antenna expand symmetrically on both sides of the support beam. The two antennas are in contact at the center. This bow tie antenna is sometimes called a butterfly antenna because it resembles a butterfly with its wings spread [13].

The bow tie antenna is a Ultra High Frequency (UHF) dipole antenna. Bow tie antennas are like log periodic antennas. This bowtie antenna's inner width is 0.11 cm, outer width is 1.94 cm, arm length is 2.15 cm, and port gap width is 0.11 cm. Also, the substrate height is 0.1575 cm, and substrate (X) and (Y) 9 cm. Bowtie antenna analysis results show that max 30 dBm in the Figure 10.

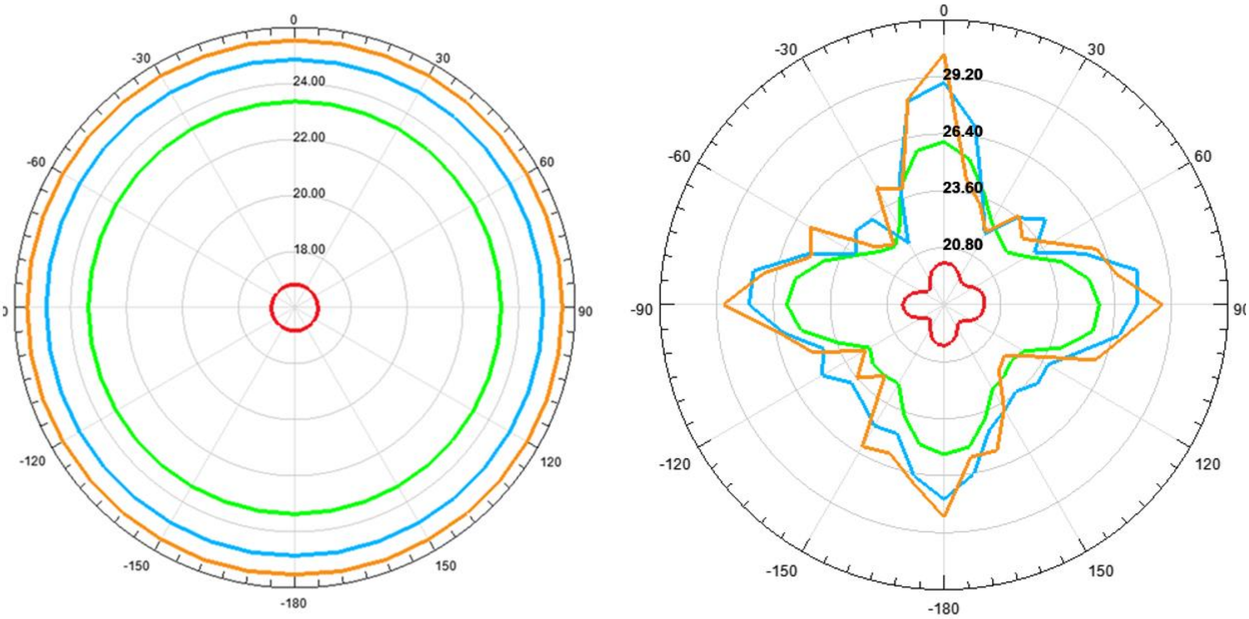


Figure 10. Bowtie antenna RCS results.

The radar cross section formula of antenna for the maximum gain=2.31,

$$\sigma = \frac{\lambda^2 G^2}{\pi} = \frac{(0.5)^2 5.33}{3,14} = 0.42 \text{ dB}m^2 \quad (23)$$

In the Table 2, shows that radar cross section values for microstrip antenna, printed dipole antenna and bowtie antenna in the 2GHz.

Table 2. Phi degree versus monostatic radar cross section values(dBm) for 3 different antenna types.

Phi (Deg)	Microstrip antenna (2 GHz)	Printed dipole antenna (2 GHz)	Bow tie antenna (2 GHz)
0	31.4	25.36	26.01
90	43.5	35.11	25.65
180	31.24	28.97	25.35
270	29.5	27.22	25.74
360	31.85	27.14	26.01

4. ANALYSIS OF CONFORMAL PATCH ANTENNA ON THE MISSILE

In this part of the thesis, seven microstrip antennas and two microstrip antennas analyzed on MALD platform to imitate target radar cross section values. According to Table 3, different radar cross section rates seen due to shape, material etc. [14, 15].

Table 3. Radar cross section values of fighter planes.

Target	RCS (m^2)
B-52 Stratofortress	100-125
C-130 Hercules	80
F-15 Eagle	10-25
F-4 Phantom	6-10
F-16A	5
F-35 Lightning II	0.0015-0.005
F22 Raptor	0.00001

Firstly, two microstrip antennas used on the MALD platform to imitate F-16A and antennas covered to body of missile in Figure 11. According to analysis results calculation of radar cross section for 37 dBm,

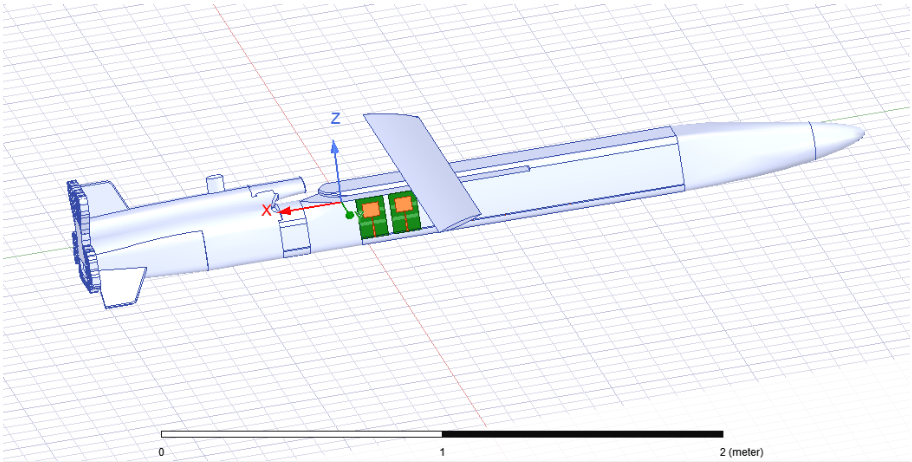


Figure 11. MALD platform with 2 phased array antennas.

$$\text{dBm} = \text{dB} + 30$$

$$\text{RCS} = 10^{(dB/10)}\, m^2 \quad \text{so, RCS} = 5\, m^2 \tag{24}$$

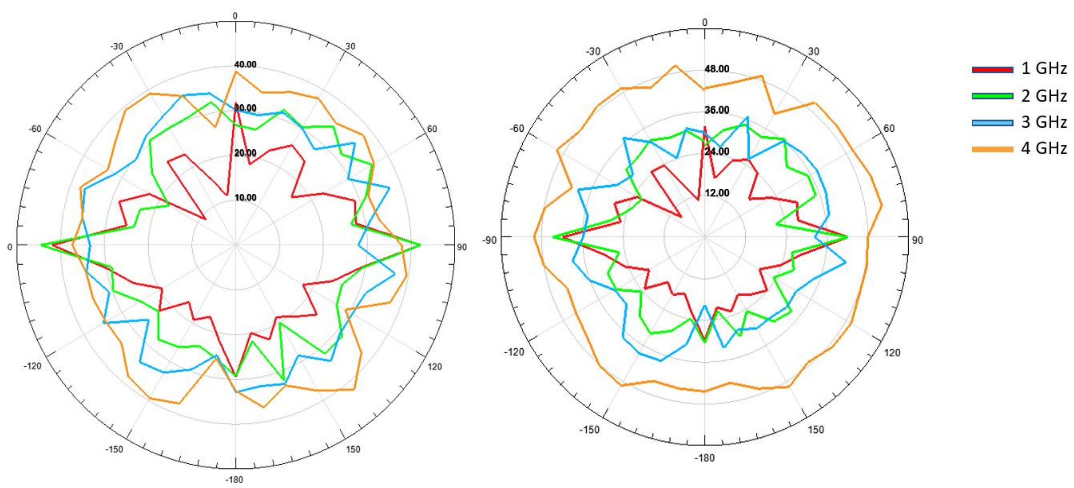


Figure 12. MALD platform RCS results with 2 microstrip antennas.

Secondly, seven microstrip antennas used on the MALD platform to imitate B-52 Stratofortress. Seven microstrip antennas, which had good results before, were wrapped conformally to the missile's fuselage in Figure 13. A separate port was created for each antenna, and the distance between them was equal. Analysis performed for 1,2,3 and 4 GHz. As seen in Figure 12, if antennas are not active, the result of the missile RCS is on the left side, and if antennas are active, the result of the missile radar cross section in the right side.

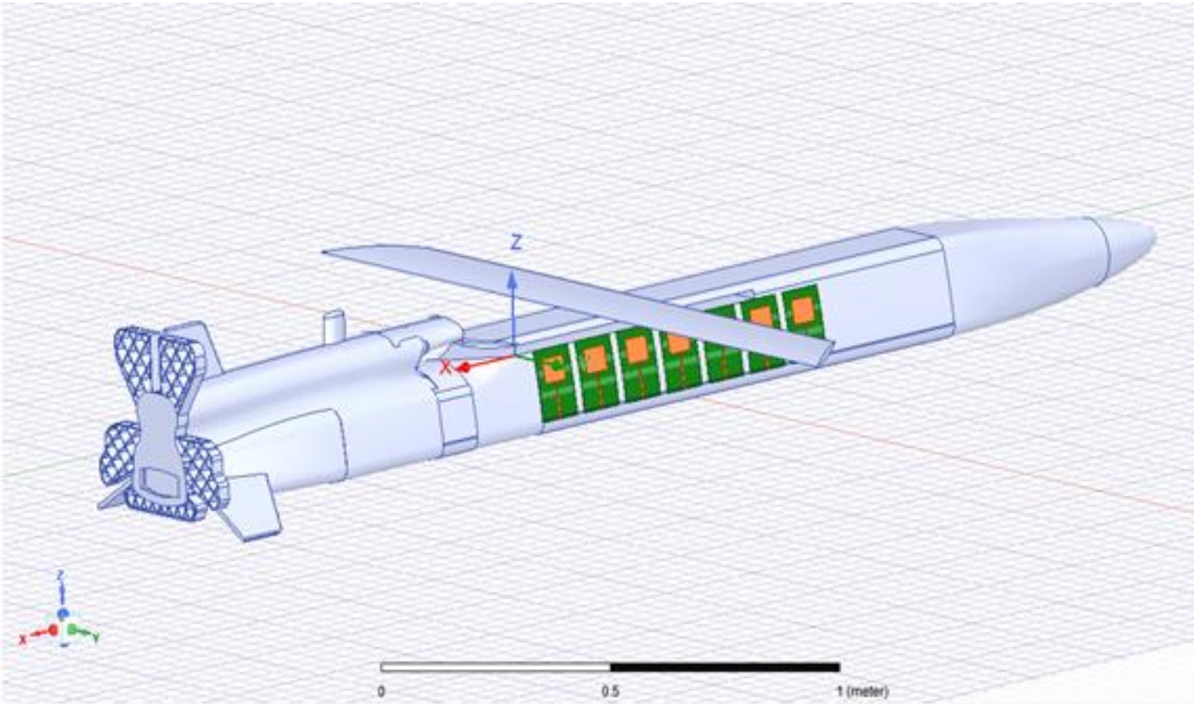


Figure 13. MALD platform with 7 phased array antennas.

According to radiation pattern results, all frequencies were increased, especially 4 GHz, as seen in Table 1 and Table 4. An intense radar cross-sectional area increase is observed in the wing region of the missile in Figure 14. MALD platform RCS results with 7 antennas.

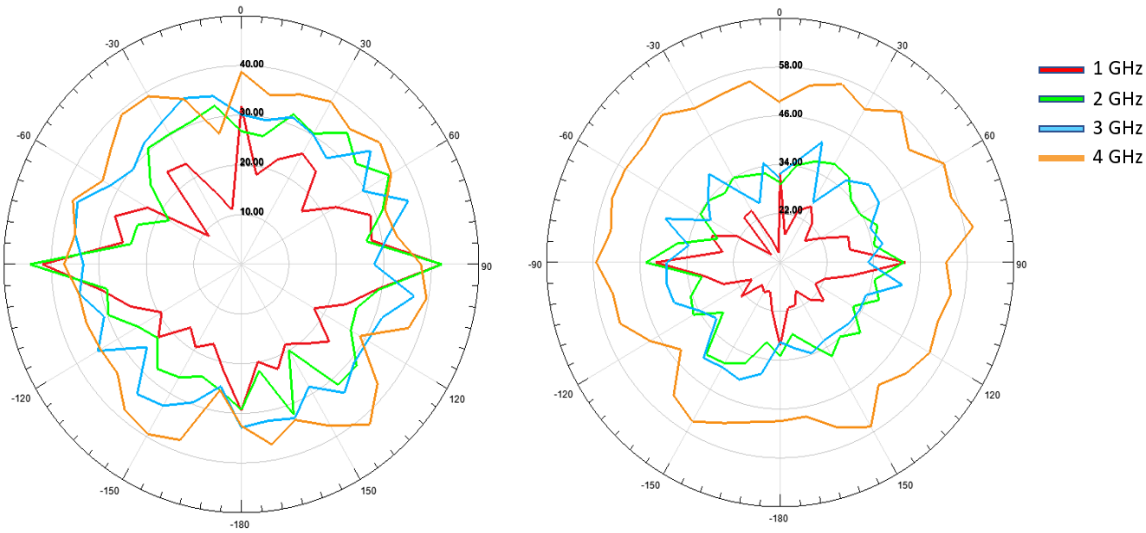


Figure 14. MALD platform RCS results with 7 microstrip antennas.

Table 4. Phi degree versus monostatic radar cross section values(dBm) for phase array antenna on the missile.

Phi (Deg)	1 GHz (dBm)	2 GHz (dBm)	3 GHz (dBm)	4 GHz (dBm)
0	31.48	29.1	31.77	49.68
90	42.21	41.71	32.56	52.62
180	30.45	33.01	29.59	48.98
270	41.94	44.43	39.09	57.23
360	31.9	29.57	30.59	49.72

Average radar cross section value of missile is 50 dBm so 20 dB. Radar cross section result converted in decibels to square meters. MALD platform with 7 microstrip antennas has average 100 m^2. If number of antennas is decrease, RCS value down from 20 dB to 7 dB. According to Formula 24, RCS value found 5 m^2 for 2 microstrip antennas. By reducing the number of antennas, radar cross section value can increase or decrease [16].

5. CONCLUSION

Decoys have played an important role in electronic countermeasures and deception, and much work and development have been realized in the last decades. They are used to give the appearance of attacking in enemy airspace by mimicking the fighter's radar signature and flight profile. In this article, Miniature Air-Launched Decoy (MALD) platform was used. It has a lower radar detection probability than a fighter due to its lower radar cross section (RCS). This situation raises suspicion and provides a basis for distinguishing between MALD and combatants. Therefore, the emission and RCS of the MALD system should be fighter-like. In this study, a method presented to improve the RCS of her MALD system using a phased array antenna. For this purpose, a method was developed to cover the MALD platform's surface with a phased array antenna. So far, some studies have been done to reduce the radar cross-section, but in this article, analyses were made to increase the radar cross-section. Because as the radar cross-section of this platform, which copies the radar track of the fighter plane, increases, the rate of misleading the enemy will increase, and the enemy will have difficulty detecting the location of the fighter plane. The analyses were evaluated between 1 GHz and 4 GHz because of the frequency of L-S band (1-4 GHz) early warning radars. This article presents and compares the analysis of three antenna types to increase the radar cross-section of a missile air-launched decoy platform. According to the results, the phased array microstrip patch antenna provides approximately 15 dBm gain, the dipole antenna provides 8 dBm gain, and the Bowtie antenna provides 5 dBm gain. So, a microstrip antenna was selected for the phase array antenna structure, and this antenna wrapped the body of the missile. Results show that phase array microstrip antenna increases the radar cross-section rate of missiles. When look at the radar cross-section values of warplanes, it was seen that the radar cross-section values are low in Table 4. To strengthen the analysis results obtained, the radar cross-sectional area level can be lowered further and brought closer to the radar cross-section of the aircraft to be simulated. In future studies, the number of microstrip antennas can decrease, and different microstrip antenna models can evaluate for the radar cross-section analysis.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study.

REFERENCES

[1] S. Genovesi, F. Costa, and A. Monorchio, "Wideband radar cross section reduction of slot antennas arrays," *IEEE transactions on Antennas and Propagation*, vol. 62, no. 1, pp. 163-173, 2013. https://doi.org/10.1109/tap.2013.2287888

[2] M. A. Alves, G. G. Peixoto, and M. C. Rezende, "Simulations of the radar cross section of a generic air-to-air missile coated with radar absorbing materials," in *2007 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference. IEEE*, 2007, pp. 603-606.

[3] K. Rohit, J. Vineetha, and S. Hema, "Radar cross section analysis of multi-layered resistive material based planar/conformal radar absorbing structures," in *IEEE International Conference on Electronics, Computing and Communication Technologies*, 2021, pp. 1-4.

[4] G. S. B. Rao, S. Nambari, S. Kota, and K. S. R. Rao, "Monostatic radar cross section estimation of missile shaped object using physical optics method," presented at the In IOP Conference Series: Materials Science and Engineering (Vol. 225, No. 1, p. 012278). IOP Publishing, 2017.

[5] K. Iwaszczuk, H. Heiselberg, and P. U. Jepsen, "Terahertz radar cross section measurements," *Optics Express*, vol. 18, no. 25, pp. 26399-26408, 2010.

[6] H. J. K. John, "Close-in jamming takes off," *Journal of Electronic Defense*, vol. 36, no. 7, pp. 26–33, 2013.

[7] Raytheon, "Raytheon to integrate miniature air launched decoy on remotely piloted aircraft platform, ENP newswire," Retrieved: https://link.gale.com/apps/doc/A318819869/ITOF?u=baskent&sid=ebsco&xid=5570ff88. 2013.

[8] N. Herscovici, "New considerations in the design of microstrip antennas," *IEEE Transactions on Antennas and Propagation*, vol. 46, no. 6, pp. 807-812, 1998. https://doi.org/10.1109/8.686766

[9] S. Meerabeab, V. Jantarachote, and P. Wounchoum, "Design and parametric study of a suspended conformal patch antenna," in *19th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, ECTI-CON*, 2022.

[10] Shanghai DIAnji university, "School of electronics and information, institute of electrical and electronics engineers, and M. IEEE systems," in *2018 5th International Conference on Systems and Informatics : ICSAI 2018, Jinyuanbao Hotel, Nanjing, China, 10-12 November*, 2018.

[11] J. Chen *et al.*, "A beam position design algorithm for space-based early warning radar," in *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS. IEEE*, 2021, pp. 5016-5019.

[12] J.-M. Floc'h, A. E. S. Ahmad, J.-M. Denoual, and H. Rmili, "Design of printed dipole antenna with reflector and multi-directors," *International Journal on Communications Antenna and Propagation*, vol. 2, no. 6, pp. 407-413, 2012.

[13] H. Liu, H. Jiang, X. Guan, J. Lei, and S. Li, "Single-feed slotted bowtie antenna for triband applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 1658-1661, 2013. https://doi.org/10.1109/lawp.2013.2294751

[14] D. K. Barton and S. A. Leonov, *Radar technology encyclopedia*. Boston, London: Artech House, 1997.

[15] R. Doug, *Stealth warplanes*. Oceola, Wi: Zenith Press, 2001.

[16] V. K. Sutrakar, "Radar cross-section of a fighter aircraft at broadband frequencies ERC StG CA2PVM view project radar cross-section of a fighter aircraft at broadband frequencies," in *International Conference on Antenna Test and Measurement Society 2016 At: Goa, India*, 2016.