Journal of Naval Science and Engineering
2013, Vol.9, No.2, pp. 72-87

RADAR CROSS SECTION REDUCTION

Hakan UÇAR, Lt.

Istanbul Naval Shipyard Design Project Office
Pendik, Istanbul, Turkiye
hkucar@gmail.com

Abstract

The development of sophisticated detection systems threatens to reduce the mission effectiveness of weapon platforms. Therefore, increasing survivability by reducing detectability has become very important subject for the designers giving deep attention to methods of reducing detectability. As far as radar signature is concerned, there are four basic techniques for radar cross section reduction (RCSR); shaping, radar absorbing materials, passive cancellation and active cancellation. Of the four, the use of shaping and radar absorbers are the most effective. Shaping is typically available only for systems still in the design stage, because it can seldom be exploited for vehicles already in production. We can use radar absorbing materials where shaping is not efficient alone. Active cancellation seems to be the most effective for low-frequency RCSR, where use of absorber and shaping become very difficult. Reduction methods tend to be narrowband and effective only over limited spatial regions. The methods must be chosen based on the platform's missions and expected threats. Although we focus on the radar signature in this paper, we must also consider the other signatures (e.g., infrared, acoustic, magnetic, optical) and balance all signatures and threats for signature control.

RADAR KESİT ALANI AZALTIMI

Özetçe

İleri derecede geliştirilmiş hedef tespit sistemleri, silah platformlarının verimliliğini düşürmekte ve bu nedenle tespit edilebilirliği azaltmak suretiyle hayatı idameyi artırmak tasarımcılar için çok önemli bir konu olmakta ve tespit edilebilirliği düşürme metotları üzerine dikkatle durulmaktadır. Radar izi söz konusu olduğunda ise radar kesit alanını düşürmek için 4 temel teknik mevcuttur; şekillendirme, radar emici malzemeler, pasif ve aktif iptal etme. 4 temel *teknikten şekillendirme ve radar emicilerin kullanılması en efektif yöntemlerdir. Şekillendirme genellikle dizayn aşamasında olan sistemler için kullanılır çünkü üretilmiş olan gemiler ve sistemler için nadiren şekil değiştirilebilmektedir. Şekillendirmenin efektif olmadığı yerlerde radar emici malzemeler kullanılabilir. Aktif iptal etme, şekillendirme ve emicilerin kullanımının oldukça zor olduğu düşük frekans RKA için en verimli yöntem olarak görülmektedir. Radar kesit azaltım metotları darbandda ve limitli bölgelerde efektif olmaktadır. Dolayısıyla, platformun görevleri ve beklenen tehditlerine istinaden metot seçimi yapılmalıdır. Ayrıca bu makalede radar izine odaklanmış olsak da, diğer izleri (kızılötesi, akustik, manyetik, optic vs) de dikkate almalı ve iz yönetimi çerçevesinde tüm izleri ve tehditler hesaba katılmalıdır.*

Keywords: *Radar cross section, radar signature, reduction methods.*
Anahtar Kelimeler: *Radar kesit alanı, radar izi, azaltım metotları.*

1. INTRODUCTION

Radar cross section (RCS) is the measure of a target's ability to reflect radar signals in the direction of the radar receiver, i.e., it is a measure of the ratio of backscatter power per steradian (unit solid angle) in the direction of the radar (from the target) to the power density that is intercepted by the target. We can define the RCS of a target as a comparison of two radar signal strengths. One is the strength of the reflected signal from a target, the other is the strength of the reflected signal from a perfectly smooth sphere of cross sectional area of 1 m^2 as shown in Figure 1 [1].

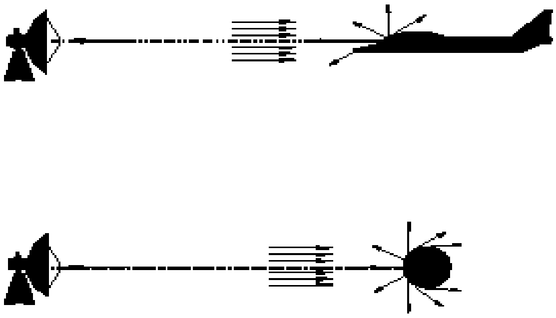

Figure 1. Concept of Radar Cross Section

Upon the development of radar during World War II, radar cross section (RCS) reduction has continued to be pursued as a passive technique for reducing detectability. Since the budget of the governments are tight and the sensor based missiles perceives the target signature, the significance of RCS reduction increases. The advantages of RCS reduction (RCSR) are as follows;

1. RCSR prevents or delays detection by radar.
2. RCSR prevents or makes a correct target classification difficult.
3. RCSR prevents the lock-on of radar seeker heads or reduces the lock-on distance.
4. RCSR increases the protective range of ECM.
5. RCSR decreases the protective chaff mass and increases the efficiency of chaff.
6. Shortly, RCSR increases the survivability.

2. METHODS OF RCS REDUCTION

There are four basic techniques for reducing radar cross section:

1. Shaping;
2. Radar absorbing materials (RAM);
3. Passive cancellation;
4. Active cancellation.

Application of each of these methods involves a compromise in performance in other areas. For instance, there are limitations to modification of an aircraft's shape from the aerodynamic optimum. Sharply angled facets may be desirable from a RCS perspective, but they degrade the aircraft's maneuverability and handling characteristics [2].

Each method has advantages and disadvantages. The two most practical and most often applied RCS reduction (RCSR) techniques are listed first, shaping and radar absorbing materials. In current RCS designs, shaping techniques are first employed to create a planform design with inherently low RCS in the primary threat sectors. Radar absorbing materials are then used to treat areas whose shape could not be optimized or to reduce the effects of creeping waves or traveling waves on the signature. The combination of RAM and shaping can often be exploited when neither can satisfy the objectives alone [4].

2.1. Shaping

The overall size of a military vehicle, ship or plane cannot be altered much, within the confines of operational capabilities. Thus the geometric cross section is not easily reduced. The objective of shaping is to orient the target surfaces and edges to deflect the scattered energy in directions away from the radar. The success of shaping depends on the existence of angular sectors over which low radar cross section is less important than over others.

Figure 2 illustrates the RCS reduction available by the use of shaping. The curves plotted are based on theory and measurements and show how the nose-on (axial) RCS varies with the electrical size of each of the six rotationally symmetrical metallic bodies [3].

In the Figure 2, except for the sphere, whose RCS is shown by the uppermost trace, all the objects have the same nose angle (40°), and of the six shapes the ogive exhibits the lowest RCS. Thus, at least along the axes of these particular bodies, the RCS can be minimized by selecting the appropriate surface profile.

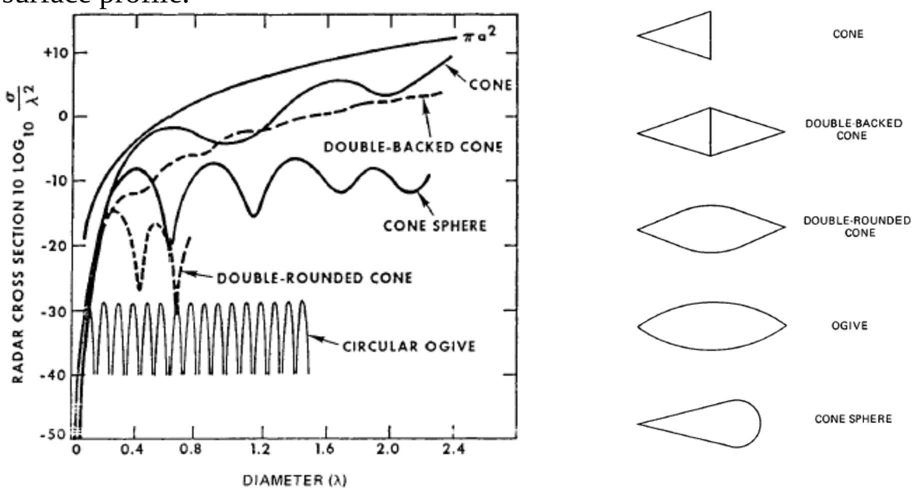

Figure 2. RCS of a collection of bodies of revolution of similar size and projected area.

The attainment of low echoes over a range of aspect angles is usually accompanied by higher echo levels at other angles. Thus, the selection of an optimum shape should always include an evaluation of the variation of the RCS over a range of aspects wide enough to cover the anticipated threat directions. This implies the capability to measure the RCS patterns of a collection of objects with candidate surface profiles or the capability to predict those patterns, or both.

Two approaches may be taken in the application of shaping. One is to replace flat surfaces with curved surfaces and thereby eliminate narrow but intense specular lobes. While this reduces the magnitudes of specular echoes, it increases the general echo levels at nearby aspect angles. The other approach is to extend flat and singly curved surfaces so as to further narrow the specular lobe even if this increases its intensity [3]. It is usually best to keep large surfaces as flat and smooth as possible so that the specular flash is confined to a very narrow angular region. The larger the area, the higher the maximum RCS, and the faster it drops off [2].

Shaping is usually difficult to exploit or expensive to implement for vehicles or objects already in production. This is so because the vehicle configuration and profile have been selected and optimized for specific mission objectives; changes in the configuration are likely to impair the mission capabilities of the vehicle. Furthermore, shaping is not very effective for bodies that are not electrically large.

2.2. Radar Absorbing Material (RAM)

The second method of RCS reduction is the use of radar absorbing materials (RAM). As the name implies, the purpose of the radar absorber is to soak up incident energy and thereby reduce the energy scattered or reflected back to the radar.

At radar frequencies, there are two primary approaches to reducing reflections from a structure: absorption and cancellation. Absorption is the transfer of energy from the wave to the material as it passes through [2]. Radar energy is absorbed through one or more of several loss mechanisms, which may involve the dielectric or magnetic properties of the material. The loss is actually the conversion of radio frequency energy into heat, and although most absorbers do not dissipate enough energy to become even detectably warm when illuminated by a radar, this is nevertheless the mechanism by which they operate [5]. The wave must travel many wavelengths before appreciable attenuation takes place as shown in Figure 3.

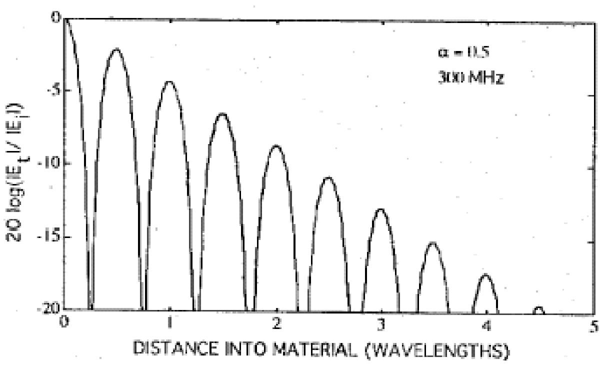

Figure 3. Attenuation of a wave as it penetrates a lossy material

Most absorbers are designed to reduce specular reflections from metallic surfaces, but some have been designed for nonspecular scattering. The RCS was commonly reduced by adding a resistive film above the surface or by coating it with a dielectric. These are referred to as a *Salisbury Screen* and *Dallenbach layer*, respectively.

2.2.1. Salisbury Screen:

The Salisbury Screen is the simplest specular absorber. A thin resistive sheet is mounted a quarter wavelength above a metal surface, shown schematically in Figure 4 [6].

The resistive sheet is introduced to cancel reflections from the target surface. The transmission-line analogy is a lumped resistive element located a quarter wavelength toward the generator from a short circuit. Because the short circuit transforms to an open circuit at the lumped element, the effective impedance terminating the line is the resistive element itself. The reflection due to this termination becomes zero when the impedance of the element is identically the characteristic impedance of the line, Z_0. Because the impedance of free space is 377 ohms, the resistive sheet should have a resistivity of 377 ohms per square [3]. The theoretical performance of the device for three values of resistivity is shown in Figure 5.

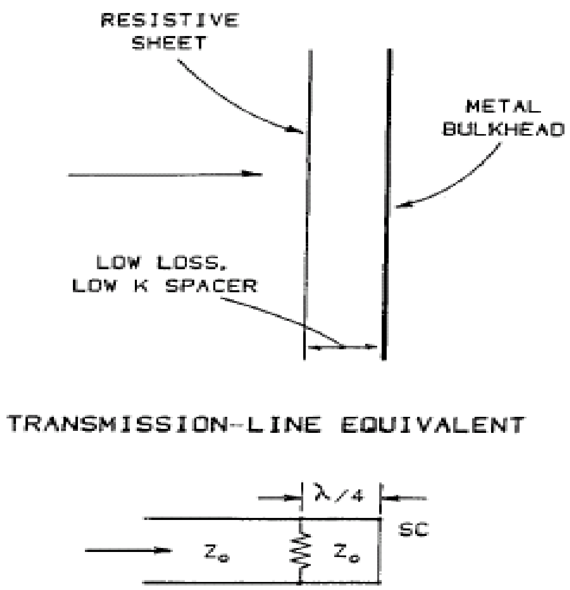

Figure 4. The Salisbury Screen and its transmission line equivalent. K is the dielectric constant of the spacer between the resistive sheet and the metal plate.

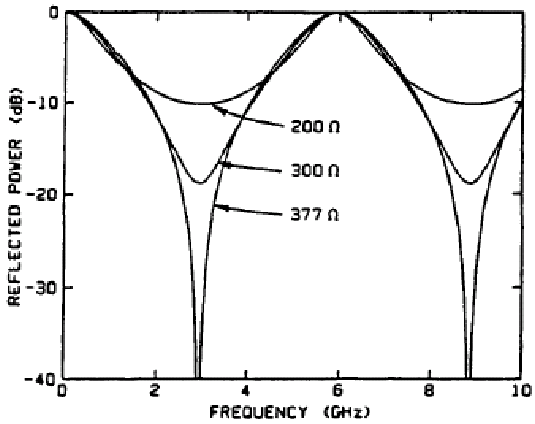

Figure 5. Performance of the Salisbury Screen

2.2.2. Dallenbach Layer:

The Dallenbach Layer is also a simple absorber. The material is a mixture of compounds designed to have a specified index of refraction [3]. The Dallenbach Layer is illustrated schematically in Figure 6 [2]. The Dallenbach Layer design may include materials with magnetic losses as well as carbon particles responsible for electric losses. The electric and magnetic susceptances (relative permittivity and relative permeability) therefore have imaginary components, resulting an index of refraction with an imaginary component. The resulting imaginary part of the propagation constant attenuates waves traveling through the material [3]. Figure 7 shows the reflection coefficient of Dallenbach Layers as a function of thickness for several values of permittivity and permeability [2]. The thickness should be as small as possible to minimize the additional size and weight of the coating.

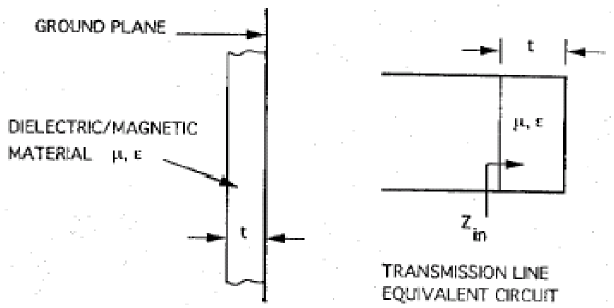

Figure 6. Dallenbach Layer

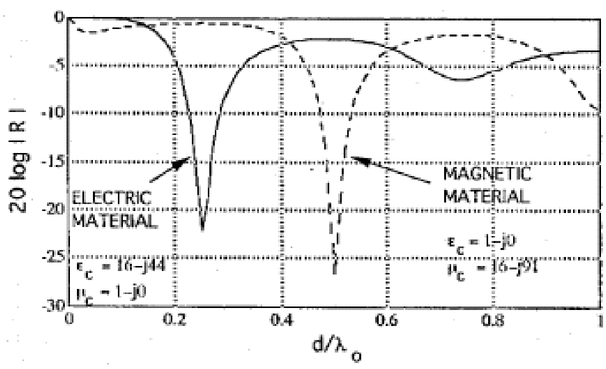

Figure 7. Performance of Dallenbach Layers

Carbon was the basic material used in the fabrication of early absorbers because of its imperfect conductivity, and it continues to be important today. These materials are not easily applied to operational weapons platforms. They are usually too bulky and fragile in operational environments [5].

Magnetic absorbers are used more widely for operational systems. The loss mechanism is primarily due to a magnetic dipole moment, and compounds of iron are the basic ingredients. Magnetic materials offer the advantage of compactness because they are typically a fraction of the thickness of dielectric absorbers. However, magnetic absorbers are heavy because of their iron content and are inherently more narrowband than their dielectric counterparts. So, iron is not suitable for RCS applications.

The other material used for RCS application is the composite material. A composite is a material which is designed to display a combination of the best characteristics of each of the component materials [7]. These properties are physical, mechanical, thermal, and electrical properties. Composite materials have replaced metals in most applications. The use of composites has both advantages and disadvantages in RCSR application. Their advantages are primarily mechanical; increased strength, reduced weight, resistance to the environment, increased fatigue life, thermal stability, and ease of manufacture. The reflection coefficients of composites are usually less than those of metals. Traveling waves are also problems because the surface impedance has a larger real part than a good conductor and the reactive part is not inductive. The other disadvantage is that the composites are penetrable. Significant field strengths can exist in the interior of composite bodies. So, interior metal structures will scatter. The most common composites used in the aircraft industry are graphite/epoxy, boron/epoxy, aramid/epoxy, and glass/epoxy [2].

2.3. Passive Cancellation

In passive cancellation, the basic concept is to introduce an echo source whose amplitude and phase can be adjusted to cancel another echo source. The target with the scattering element is called the *loaded body*, as opposed to the bare target, which is the *unloaded body* [2]. This method is also known as *impedance loading*.

This technique is effective over only a narrow frequency band and is usually limited to a small spatial sector. Unfortunately, even for simple bodies, it is extremely difficult to generate the required frequency dependence for this built-in impedance, and the reduction obtained for one frequency in the spectrum rapidly disappears as the frequency changes.

Typical weapon platforms are hundreds of wavelengths in size and have dozens of echo sources. It is not practical to devise a passive cancellation treatment for each of these sources. As a consequence, we can discharge the most part of the method as a useful RCSR technique [5].

2.4. Active Cancellation

Active cancellation, or *active loading*, is even more ambitious than passive loading [5]. In this method, the target must emit the radiance in time coincidence with approaching pulse whose amplitude and phase cancel the reflected energy.

In active cancellation, a target transmits a signal which mimics the echo that the radar will receive - but one half wavelength out of phase, so that the radar sees no return at all. The advantage with this technique is that it uses very low power (compared with conventional EW) and provides no clues to the target's presence. The challenge is that it requires very fast processing and that poorly executed active cancellation could make the target more, rather than less, visible to the radar.

Active cancellation appears most suitable for low-frequency RCSR, where use of absorber and shaping become very difficult and scattering patterns exhibit broader lobes. Research on this technique is likely to continue because other practical means of RCSR are also difficult to apply for low frequencies. Nevertheless, it is worthwhile to remember that an active canceler that is not working correctly has another name—it is called a beacon! [5].

2.5. The Penalties of RCSR

The requirement for reduced radar echo usually conflicts with traditional requirements for structures. As a result, the RCS reduction increases the cost of the overall system. The other penalties of RCS are;

1. Reduced payload
2. Reduced range
3. Added weight
4. Increased maintenance.

The importance of each factor can change depending on the mission of the platform. RCS reduction cannot always be justified, at least in terms of improved detection range. For example, Georgia Tech calculated the detection range for a hypothetical sea target ingressing against shore-based radars. The detection range was decreased less than 10% despite drastic changes in the target to reduce its radar echo [5]. Because, the assumed threats were very sensitive and the target was detected as it came over the horizon, treated or not. On the other hand, RCSR for that platform may well have been justified when considered in concert with electronic countermeasures.

As a consequence, the designers always have to make trade-offs with respect to a large number of operational characteristics.

3. CONCLUSION

Although four methods of RCS reduction actually are available, only two methods (shaping and radar absorbers) have been demonstrated to be the most effective. The objective of shaping is to select the surface profiles of a target so as to deflect reflected radar waves in any direction except back to the radar. When this method is not effective or feasible, the designers may coat sensitive parts of the target with radar-absorbing material.

These options cost a very high price, including nonrecurring engineering costs, recurring maintenance costs, and reduced effectiveness of other mission functions. In addition to the shaping and radar absorbers, passive and active cancellation methods are the other options to avoid detection or to break track, including tactics and electronic countermeasures. Active cancellation appears most suitable for low-frequency RCSR, where use of absorber and shaping become very difficult.

The system designers must consider all of them and not RCS reduction exclusively. For a successful RCS reduction, the system designers require the followings;

1. A precise knowledge of the signature to be expected
2. Good knowledge of effective measures for the reduction of signatures
3. Examination of the effectiveness of RCS reduction

The system designers also consider the basic rules for a successful RCS reduction.

4. Design for specific threats when possible to minimize cost.
5. Orient large, flat surfaces away from high-priority quiet zones
6. Avoid round surfaces
7. Avoid 90^0 corners to prevent multiple reflections.
8. Avoid discontinuities in geometry and materials to minimize diffraction and traveling wave radiation.
9. Use as few surfaces as possible with different slopes and directions.
10. Use lossy materials or coatings to reduce specular/traveling wave reflections.
11. Maintain tolerances on large surfaces and materials.
12. Treat trailing edges to avoid traveling wave lobes.
13. Avoid exposing cavity inlets; use a mesh cover, or locate the inlets out of view of the radar.
14. Shield high-gain antennas from out-of-band threats

REFERENCES

[1] "Radar Cross Section", *Electronic Warfare and Radar Systems Engineering Handbook*, Avionics Department of the Naval Air Warfare Center Weapons Division, 2003.

[2] David C. Jenn, *Radar and Laser Cross Section Engineering*, Ohio: AIAA Education Series, 1995.

[3] Eugene F. Knott, “Radar Cross Section”, *Radar Handbook*, McGraw-Hill, 1990.

[4] J.W. Crispin, A.L. Maffett, “The Radar Cross Section of Surface Effect Ships,” *Report APL SES-001*, *Applied Physics Laboratory*, John Hopkins University, December 1972.

[5] J.F. Shaeffer, M.T. Tuley, E.F. Knott, *Radar Cross Section*, SciTech Publishing, 2004.

[6] W.W. Salisbury, *Absorbent Body for Electromagnetic Waves*, US Patent 2, 599, 944, June 1952.

[7] William D. Callister, *Materials Science and Engineering*, New Jersey: John Wiley and Sons, Inc., 2003.