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Development of Algorithm for RCS Estimation of a Perfectly Conducting Sphere using Spherical Polar Scattering Geometry

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Abstract
Stealth Technology plays a major role in order to make the targets unseen by enemy Radar. In Stealth Technology there are many signatures to be managed for a target in which most Radar systems use RCS as a means of discrimination of targets and classification with regard to Stealth. Spherical Polar Scattering Geometry (SPSG) is the proposed process in which the scattering coefficients $\mathbf{a_n^s}$ and $\mathbf{b_n^s}$ are defined and the physical interpretation of $\mathbf{a_n^s}$ and $\mathbf{b_n^s}$ coefficients aids in visualizing the mechanism of the scattering process. In this paper Radar Cross Section of a perfectly conducting Sphere is computed with respect to the parameters like size and frequency using Mie scattering series in which the relation was given by Kerr[1]. In this paper, an algorithm is developed for estimating RCS for a perfectly conducting Sphere at different frequencies with particular diameter and also the RCS is computed for various diameters at different band of frequencies using Spherical Polar Scattering Geometry. RCS treatment in this paper is based on Radar frequencies ranging from 0.1 Ghz to 40 Ghz.

Keywords : Radar Cross Section, Diameter

INTRODUCTION

Most radar systems use RCS as a means of discrimination of targets/objects and their classification with regard to stealth, in many cases. Therefore accurate prediction of target RCS is critical in order to design and develop robust discrimination algorithms. Additionally measuring and identifying the scattering centres (sources) for a given target aid in developing RCS reduction techniques. Radar cross section 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)[4]-[11].Stealth refers to the art of trying to hide or to evade detection. It is a low 'observable technology. There are different signatures available. Signatures are those characteristics by which weapon systems may be detected, recognized, and engaged. The modification of these signatures can improve the survivability of military or navy systems, leading to improved effectiveness. Signature detection commonly amounts to the detection of the electromagnetic signature of an object. Stealth is an assemblage of techniques, which makes a system harder to find and attack. Achieving Stealth features involves the reduction of active and passive signatures. ***Active signature*** is defined as all the observable emissions from a platform: acoustic, chemical, radar and UV etc. ***Passive signature*** is defined as all observables on a platform that require external illumination: magnetic and gravitational anomalies; reflection of sunlight and cold outer space.

Radar Cross Section Concept The RCS of a target can be viewed as a comparison of the strength of the reflected signal from a target to the reflected signal from a perfectly smooth sphere of cross sectional area of 1 m^2 as shown in Figure 1.

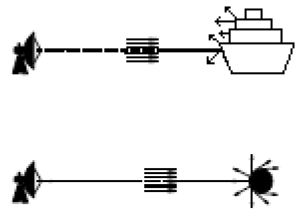

Figure 1: Radar Cross Section

The conceptual definition of RCS includes the fact that not all of the radiated energy falls on the target. A target's RCS (σ) is most easily visualized as the product of three factors

σ = **Projected cross section** x **Reflectivity** x **Directivity** .

Reflectivity The percent of intercepted power reradiated (scattered) by the target.

Directivity The ratio of the power scattered back in the radar's direction to the power that would have been backscattered had the scattering been uniform in all directions (i.e. isotropically).

MATHEMATICAL ANALYSIS ON RCS OF A SPHERE

In the case of the sphere, the scattered field must be represented in terms of θ and φ components, where θ is the bistatic angle subtended in the directions of incidence and scattering at the center of the sphere, and φ is the angle between the plane of scattering (formed by the directions of incidence and scattering) and the plane containing the incident electric field and direction of incidence. The components of the scattered field are [1],[2] and [3]

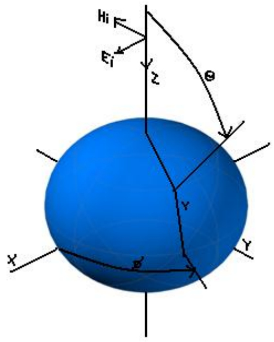

Figure 2: Spherical Polar Scattering Geometry

$$E_\theta^s = \frac{j e^{-jka}\cos\phi}{kr}\sum_{n=1}^{\infty}(-1)^n \frac{2n+1}{n(n+1)}\left[b_n \frac{\partial P_n^1(\cos\theta)}{\partial\theta} - a_n \frac{P_n^1(\cos\theta)}{\sin\theta}\right] \quad (1)$$

$$E_\phi^s = \frac{j e^{-jka}\sin\phi}{kr}\sum_{n=1}^{\infty}(-1)^n \frac{2n+1}{n(n+1)}\left[b_n \frac{\partial P_n^1(\cos\theta)}{\partial\theta} - a_n \frac{P_n^1(\cos\theta)}{\sin\theta}\right] \quad (2)$$

Where 'r' is the distance to the point of observation, 'a' is the radius of the sphere and $p_n^{'}(\cos\theta)$ is the associated Legendre function of order 'n' and degree '1' .Where 'ka' represents the size of an object. The general function is defined as

$$P_n^m(x) = \frac{(1-x^2)^{\frac{m}{2}}}{2^n n!}\cdot\frac{d^{n+m}(x^2-1)^n}{dx^{n+m}} \quad (3)$$

Kerr gives the following for the radar cross section σ of a sphere of radius a:[1]

$$\frac{\sigma}{\pi r^2} = \left(\frac{j}{kr}\right)\sum_{n=1}^{\infty}(-1)^n(2n+1)\left[\left(\frac{krJ_{n-1}(kr)-nJ_n(kr)}{krH_{n-1}^{(1)}(kr)-nH_n^{(1)}(kr)}\right)-\left(\frac{J_n(kr)}{H_n^{(1)}(kr)}\right)\right] \quad (4)$$

Where ρ=2πa/λ, λ is the wavelength, and the a_n^s and b_n^s are the terms of a "multi-pole expansion". That is these terms are proportional to the amplitudes of magnetic and electric multi-poles induced in the sphere by the incident wave. When the sphere is perfectly conducting

$$a_n^s = -\frac{j_n(\rho)}{h_n^{(2)}(\rho)} \quad (5)$$

$$b_n^s = -\frac{[\rho\, j_n(\rho)]'}{[\rho\, h_n^{(2)}(\rho)]'} \quad (6)$$

Where the primes denote differentiation with respect to the argument. The functions jn and hn2 are respectively the spherical Bessel function of the first kind and spherical Hankel function of the second kind.

The coefficients a_n and b_n are

$$a_n = -\frac{j_n(ka)}{h_n^{(2)}(ka)} \quad (7)$$

$$b_n^s = -\frac{[ka\, j_{n-1}(ka) - n\, j_n(ka)]}{[ka\, h_{n-1}^{(2)}(ka) - n\, h_n^{(2)}(ka)]} \quad (8)$$

$$H_n^{(1)}(kr) = J_n(kr) + jY_n(kr) \quad (9)$$

In which jn(x) and yn(x) are the spherical Bessel functions of the first and seco nd kinds, respectively.

DEVELOPMENT OF ALGORITHM AND FLOWCHART

Developed algorithm and flow chart for **Radar Cross Section (RCS) of Perfectly Conducting Sphere** using SPSG method called Spherical Polar Scattering Geometry method and obtained a plot for RCS of a Sphere (in dbsm) versus frequency (in Ghz) using Matlab simulation software

ALGORITHM

Step 1: Start

Step 2: Initialize the parameters λ, R=r/λ, ρ =2πr/λ, N=0, Q_{sq} =1,I_{kq} =1,y=1, sumlast=0, I_{sign}=1.

Step 3: Initialize the complex parameters like R_{Ho}, N, B_J, D_{BJ}, D_{DBJ}, B_Y, D_{DBY}, Q_{sq} , I_{sq}, y, N=N+1.

Step 4: H_{N2} =Complex (B_J,-B_y)

From Hankel function $H_n^{(1)}(kr) = J_n(kr) + jY_n(kr)$

Step 5: D $_{HN2}$ =Complex (D_{BJ}, -D_{By}) From Hankel function $(h_k^{(2)})' = j_k{}' - i y_k{}'$.

Step 6: A_{Ns}= - B_J/H_{N2} .

From coefficient $a_n^s = -\frac{j_n(\rho)}{h_n^{(2)}(\rho)}$

Step 7: B_{Ns}= - ($R_{Ho}.D_{BJ}.B_J$)/$R_{Ho}.D_{HN2}.H_{N2}$

From coefficient $b_n^s = -\frac{[\rho j_n(\rho)]'}{[\rho h_n^{(2)}(\rho)]'}$

Step 8: Term =Sign*(2N+1)*(A_{Ns}- B_{Ns})

from $(-1)^n(2n+1)(a_n^s - b_n^s)$

Step 9: Sum =Sum*term, from

$$\sum_{n=1}^{\infty}(2n+1)(a_n^s - b_n^s)(-1)^n$$

Step 10: ABSum2= ((CABSum) **2)

Step 11: Diffr =ABS (CABSum2- SumLast)/ABsum2)

Step 12: If Diffr is Yes Go to Step 13,

if No Go to Step 17

Step 13: SIGNML=$\frac{ABSUM2}{R_{Ho}*R_{Ho}}$

from $\frac{1}{\rho^2}\left|\sum_{n=1}^{\infty}(-1)^n(2n+1)(a_n^s - b_n^s)\right|^2$

Step 14: SIGMA= SIGNML*pi*RADIUS*RADIUS

from $\frac{\pi a^2}{\rho^2}\left|\sum_{n=1}^{\infty}(-1)^n(2n+1)(a_n^s - b_n^s)\right|^2$

Step 15: SIGFT=SIGMA*10,763

Step 16: Plot

Step 17: Sumlast=Absum2, Go to step 3

Step 18: Stop.

FLOW CHART

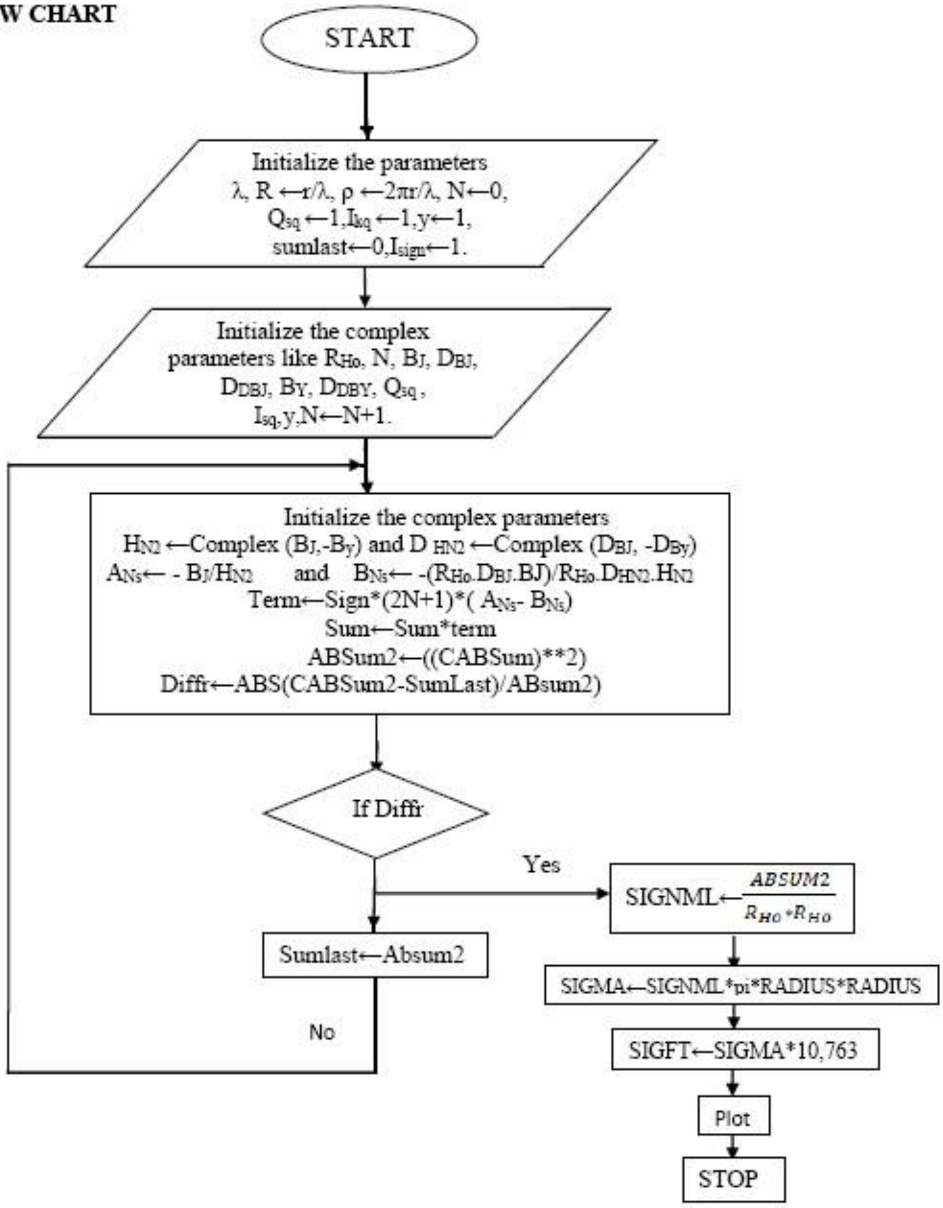

Figure 3: Flowchart for Computation of Perfectly Conducting Sphere

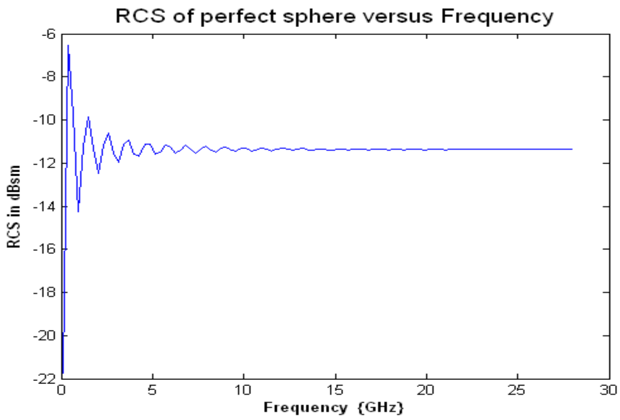

Figure 4: RCS (dbsm) verses Frequency at 12 inches Diameter

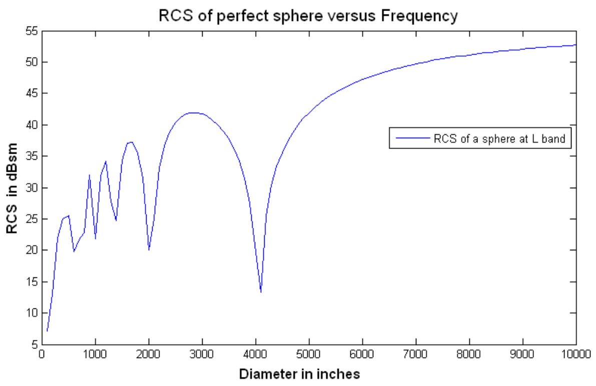

Figure 5: RCS(dbsm) versus Sphere Diameter at L band

From Figure 4 it is observed that RCS is changing with respect to frequency varying from 0.1 Ghz to 25 Ghz and RCS remains constant in the optical region the value is around -12 dbsm in optical region.From Fig5 it is observed that RCS of a Sphere is computed for different diameters ranging from 1 inch to 10,000 inches at L band frequency.

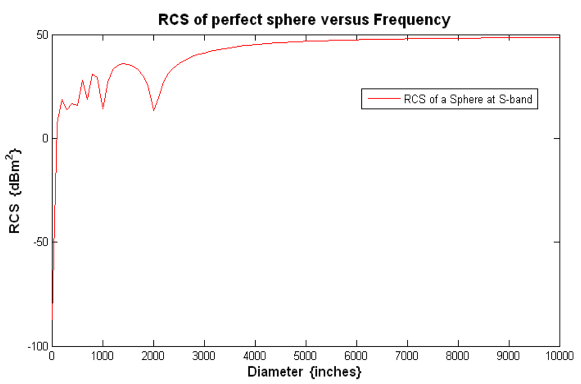

Figure 6: RCS(dbsm) versus Sphere Diameter at S band

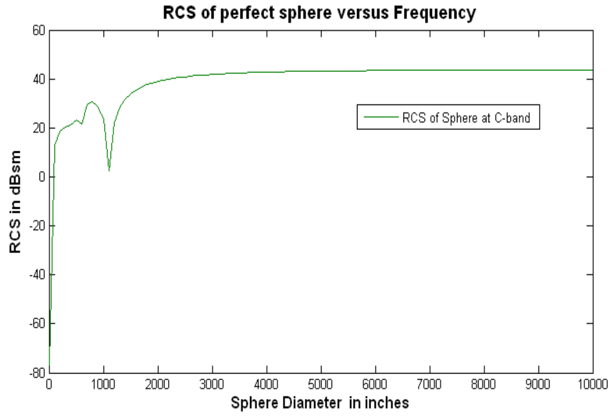

Figure 7: RCS(dbsm) versus Sphere Diameter at C band

From Fig6 it is observed that RCS of a Sphere is computed for different diameters ranging from 1 inch to 10,000 inches at S band frequency. From Fig7 it is observed that RCS of a Sphere is computed at C band frequency.

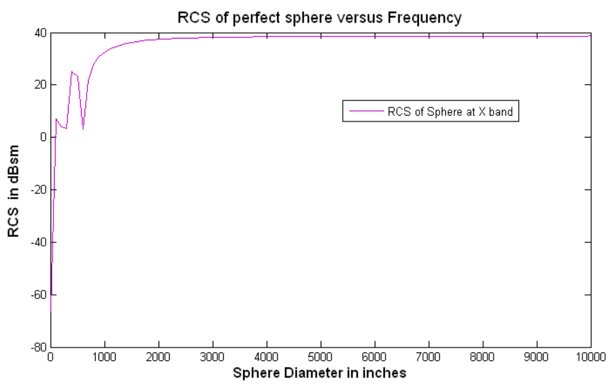

Figure 8: RCS(dbsm) versus Sphere Diameter at X band

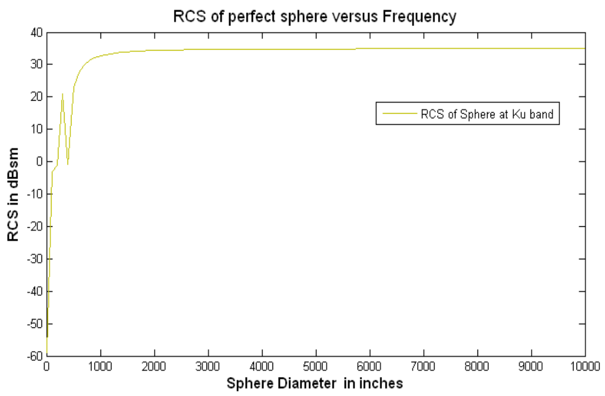

Figure 9: RCS(dbsm) versus Sphere Diameter at Ku band

From Figure 8 it is observed that RCS of a Sphere is computed for different diameters ranging from 1 inch to 10,000 inches at X band frequency. From Figure 9 it is observed that RCS of a Sphere is computed at Ku- band frequency.

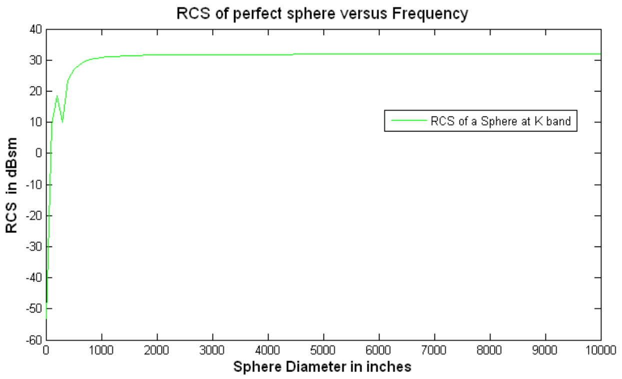

Figure 10: RCS(dbsm) versus Sphere Diameter at K band

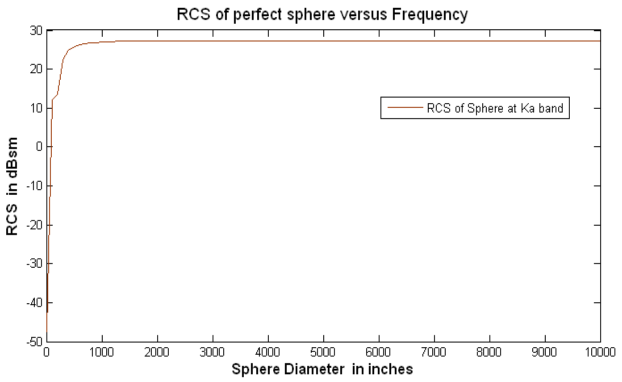

Figure 11: RCS(dbsm) versus Sphere Diameter at Ka band

From Figure 10 it is observed that RCS of a Sphere is computed for different diameters ranging from 1inch to 10,000 inches at K band frequency. From Figure 11 it is observed that RCS of a Sphere is computed at Ka band frequency.

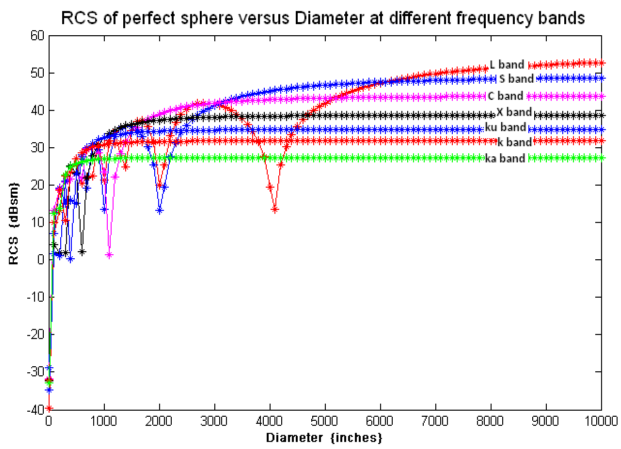

Figure 12: Comparison plot for RCS of a Perfectly conducting Sphere at different frequency bands.

From Figure 12 it is observed that RCS of a Perfect Sphere in dBsm verses Diameter of a Sphere in inches is plotted for different frequency bands.

RESULTS AND DISCUSSION

In this paper the RCS of a Sphere with 12 inches diameter has been computed for frequencies ranging from 0.1 to 40 Ghz. It is observed that some oscillations in the plot represent the Mie region. The oscillations are nothing but RCS variations due to amplitudes of magnetic and electric multipoles induced in the Sphere by the incident wave. It is observed that from Figure 5 to Figure 11 oscillations are slowly disappearing due to increase in frequency. It is observed from Figure 12 that a comparison is made for RCS of Sphere at different frequency bands. At L band Frequency RCS is more where as at Ka band Frequency RCS of Sphere is less. It is due to the fact that RCS of a Sphere is directly proportional to wavelength obtained from Kerrs relation as frequency increases, wavelength decreases and hence RCS decreases. Practically it may not be possible to measure RCS of a Sphere at bigger dimensions say 10,000 inches but theoretically it is shown how RCS of a Sphere behaves at various frequencies with respect to size by programming the Kerr's relation in Matlab.

CONCLUSION

In this paper some investigations are made on RCS of a Sphere obtained from Polar Scattering Geometry by varying the diameters ranging from 1 inch to 10,000 inches at some specified frequencies as appropriate to applications in different frequency bands like L, S, C, X, Ku, K, Ka. Results obtained through the formulations[7] show a reasonable agreement with results as obtained individually in isolation. Practically, oscillations occur in the Mie region due to creeeping waves but theoretically the Kerr relation was formulated in such a way that RCS of a sphere was oscillating in Mie region due to increase/decrease of both a_n and b_n values. The a_n and b_n values are the amplitudes of magnetic and electric multipoles induced in the Sphere by the incident wave leads to oscillations in the Mie region which are nothing but RCS variations or oscillations occur in Mie region due to creeping waves.The results are obtained through simulation carried out in Matlab.

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