

# COMPARISON OF RADAR SNR PERFORMANCE OVER SAME RANGE FOR VARIOUS SHAPED TARGET OBJECTS

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## ABSTRACT

*For a more precise detection of an object by radar, it is important to understand the significance of RCS prediction. Accurate prediction of RCS is critical in order to design and develop robust discrimination algorithms. This paper proposes the significance of RCS in radar performance by demonstrating the SNR performance of radar for some particular shaped objects. In this study we derived and simulated the RCS equation for various shaped object and thus presented an overall comparison of SNR variation for change in target shape. From simulation result it is revealed that for a large RCS, at constant range the radar gives better SNR performance.*

**KEY WORDS:** Radar Cross Section (RCS), Signal to noise ratio (SNR), Aspect angle and Backscattered RCS.

## 1.0 INTRODUCTION

Radar Cross Section (RCS) is a measure of how detectable an object is with radar. More precisely, 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 steroidal (unit solid angle) in the direction of the radar (from the target) to the power density that is intercepted by the target. Besides the above appealing properties, however, it may be said that none of the available radar waveforms may be able to guarantee the minimum required SNR for a particular RCS value at a particular detection range. This paper proposes the approximate derivation of the RCS of some objects and corresponding simulation of the RCS as a function of aspect angle. The simulations also include the impact of this variation in RCS over the relation between radar range and SNR. The proposed approximation of the equations and the overall comparison is confirmed by computer simulation using MATLAB even when the parameters vary.

## 2.0 DERIVATION OF GENERAL RCS EQUATION & SIGNIFICANCE ON RADAR RANGE EQUATION.

Let, the transmitted power from radar is  $P_t$  at a range of  $R$  where the power density of incident wave upon the target is  $P_{Di}$  and the amount of reflected power from the target is defined by[1]

$$P_r = \sigma P_{Di} \quad (1)$$

$\sigma$  denotes the target cross section. This defines the power density of the scattered waves at the receiving antenna. It follows that

$$P_{Dr} = \frac{P_r}{4\pi R^2} \quad (2)$$

Equating Eq-1 and Eq-2

$$\sigma = 4\pi R^2 \left( \frac{P_{Dr}}{P_{Di}} \right) \quad (3)$$

In order to ensure that the radar receiving antenna is in the far field (i.e. Scattered waves received by the antenna are planar), Eq-3 is modified

$$\sigma = 4\pi R^2 \left( \frac{P_{Dr}}{P_{Dt}} \right) \quad (4)$$

The RCS defined by Eq-4 is often referred to as either the monostatic RCS, the backscattered RCS, or simply target RCS.

So we can say that, RCS is a function of-

- Position of transmitter/receiver relative to target.
- Target geometry and material composition.
- Angular orientation of target relative to transmitter/receiver and antenna polarization.
- Frequency or wavelength.

Since RCS depends upon aspect angle, Constructive and destructive interference takes place between the RCS of two individual scatterers depending on the aspect angle. Again Little frequency change can cause serious RCS fluctuation when the scatterer spacing is large.

In this paper we are concerned about the dependency of target RCS over frequency and aspect angle, which consequently affects SNR performance of radar.

### 3.0 GENERAL RADAR RANGE EQUATION

For radar with an Omni directional antenna the radar range equation is

$$R_{\max} = \left( \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 k T_e B L F(\text{SNR})} \right)^{\frac{1}{4}} \quad (5)$$

Or equivalently,

$$(\text{SNR}) = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 k T_e B L R^4} \quad (6)$$

Where  $P_t$  is peak transmitted power, G is the antenna gain,  $\lambda$  is wavelength,  $\sigma$  is radar target cross section, k is Boltzman's constant,  $T_e$  is effective noise temperature, B is the radar operating bandwidth, F is system noise figure, L is radar losses and R is the target range.

### 4.0 RCS OF A CIRCULAR FLAT PLATE

The RCS of a circular flat plate target is only aspect angle dependent. For normal incidence that means zero aspect angles the back scattered RCS for a circular flat plate given in [2] is

$$\sigma = \frac{4\pi^3 r^4}{\lambda^2} \quad \theta = 0^\circ \quad (7)$$

For incidence out of  $0^\circ$  two approximations for the circular flat plate backscattered RCS are

$$\sigma = \frac{\lambda r}{8\pi \sin\theta (\tan\theta)^2} \quad (8)$$

$$\sigma = \pi k^2 r^4 \left( \frac{2J_1(2kr \sin\theta)}{2kr \sin\theta} \right)^2 (\cos\theta)^2 \quad (9)$$

Where  $k = \frac{2\pi}{\lambda}$ , and  $J_1(\beta)$  is the first order spherical Bessel function evaluated at  $\beta$ . Figure-1 shows the evaluation of RCS versus the corresponding aspect angle and Figure-2 shows the SNR performance versus the range corresponding to RCS obtained from the computer simulation using the derived approximate equations. The SNR performance compared to range is well satisfying.

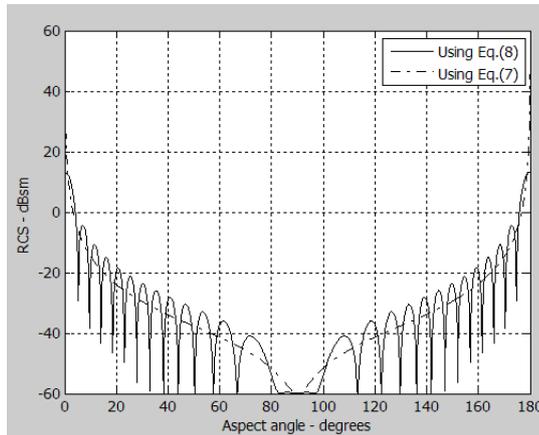


Figure-1: Backscattered RCs of a circular flat plate for different parameters ( $r = 0.125\text{m}$ ,  $f = 8\text{GHz}$ ).

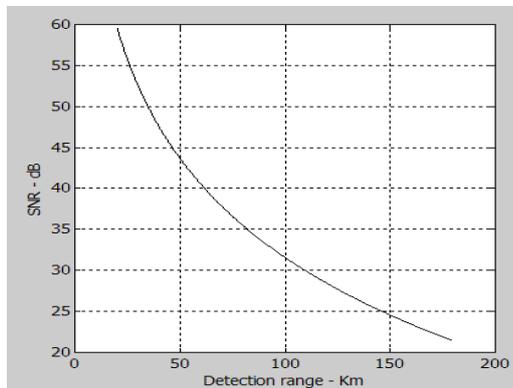


Figure-2: Typical outputs generated by the range equation for the evaluated RCS for parameters  $r = 0.125\text{m}$ ,  $P_t = 1.5\text{ Mwatt}$ ,  $f = 8\text{GHz}$ ,  $G = 45\text{ dB}$ ,  $F = 3\text{dB}$ ,  $B = 5\text{MHz}$ ,  $T_e = 290\text{K}$ ,  $L = 6\text{dB}$ ,  $R = 20\text{km} \sim 180\text{km}$ .

## 5.0 RCS OF A CYLINDER

For a circular cylinder of radius  $r$  and height  $h$ , the backscattered RCS is given [2]

$$\sigma = \frac{2\pi h^2 r}{\lambda} \quad \theta = 0^\circ \quad (10)$$

$$\sigma = \frac{\lambda r \sin\theta}{8\pi(\cos\theta)^2} \quad \theta \neq 0^\circ \quad (11)$$

The RCS plot corresponding to the equations using MATLAB is shown in Figure-3. The SNR vs. Range plot using MATLAB is shown in Figure-4. The figure indicates that RCS depends on aspect angle and the broadside speculum occurs at aspect angle of  $\frac{\pi}{2}$ . The range equation is found to be under 0dB or negative even at the lowest range calculated (20km). So this kind of object has lower range performance.

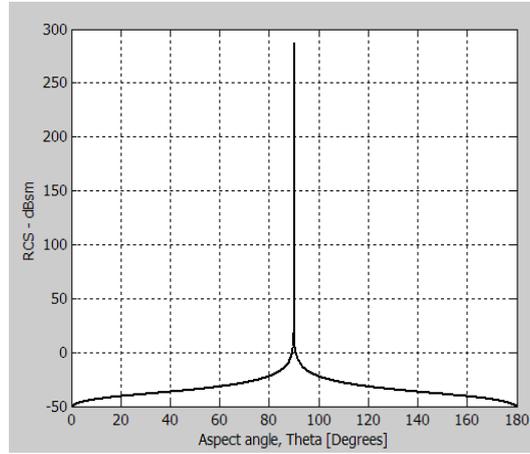


Figure-3 Backscattered RCS of a circular cylinder for different parameters ( $r = 0.125$  m,  $h = 1$  m).

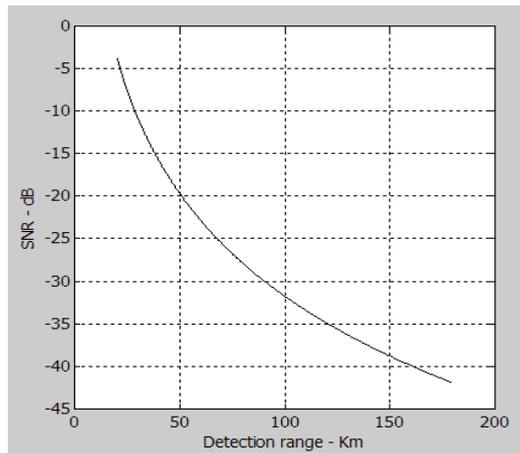


Figure-4: Range equation performance for corresponding RCS for different parameters ( $r = 0.125$  m,  $h = 1$  m,  $P_t = 1.5$  Mwatt,  $f = 8$  GHz,  $G = 45$  dB,  $F = 3$  dB,  $B = 5$  MHz,  $T_e = 290$  K,  $L = 6$  dB,  $R = 20$  km  $\sim$  180 km.)

## 6.0 RCS OF A RECTANGULAR FLAT PLATE

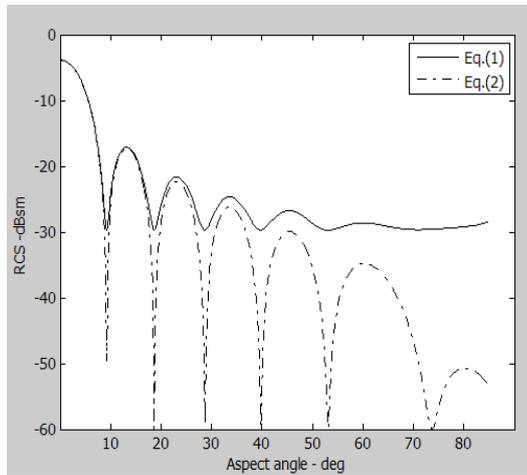
For a linearly polarized incident wave in the x-z plane, the horizontal and vertical backscattered RCS given in [3] are

$$\sigma_v = \frac{ab^2}{\lambda} \left[ \left\{ 1 + \frac{\pi}{2(2a/\lambda)^2} \right\} + \left\{ 1 - \frac{\pi}{2(2a/\lambda)^2} \right\} \cos(2ka - 3\pi/5) \right] \quad (12)$$

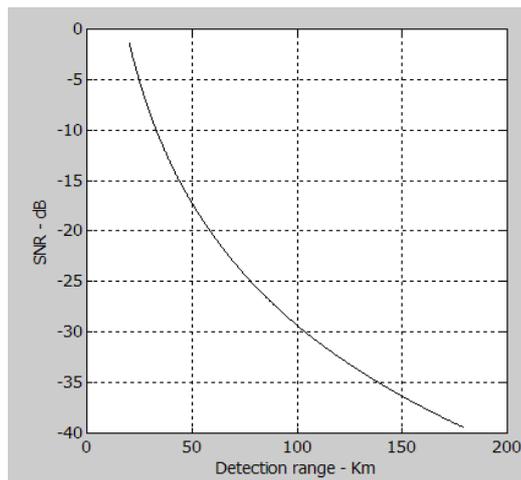
The backscattered RCS for a perfectly conducting thin rectangular plate for incident waves at any can be approximated by [3]

$$\sigma = \frac{4\pi a^2 b^2}{\lambda} \left\{ \frac{\sin(aksin\theta \cos\phi) \sin(bksin\theta \sin\phi)}{aksin\theta \cos\phi \quad bksin\theta \sin\phi} \right\}^2 \quad (13)$$

Figure-5 shows an example for the backscattered RCS of a rectangular flat plate and correspondingly Figure-6 shows the SNR performance.



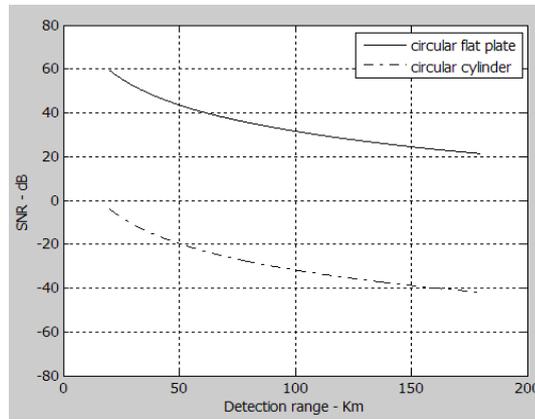
**Figure-5: Backscattered RCS of a rectangular flat plate with parameters  $a = 10.16$  cm,  $b = 5.8$  cm  $f = 8$ GHz.**



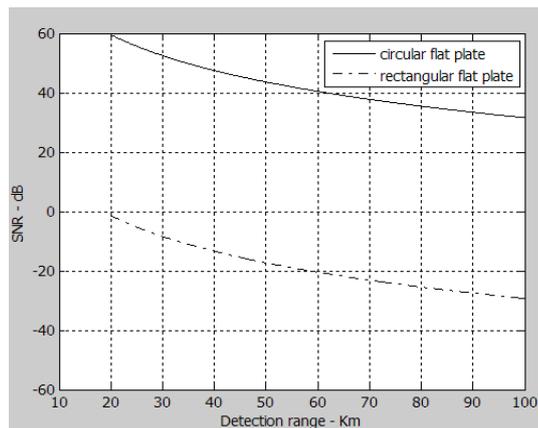
**Figure-6: SNR performance of radar for a rectangular surfaced object for different parameters ( $a = 10.16$  cm,  $b = 5.8$  cm,  $P_t = 1.5$  Mwatt,  $f = 8$  GHz,  $G = 45$  dB,  $F = 3$ dB,  $B = 5$ MHz,  $T_e = 290$ K,  $L = 6$ dB,  $R = 20$ km  $\sim 180$ km.)**

## 7.0 SNR PERFORMANCE COMPARISON AND SIMULATION

The approximate evaluation is confirmed by comparing the results obtained by the equation with those by computer simulation. Figure-7 shows a comparison between the SNR performance of radar for a circular flat plate object and circular cylindrical object, while Figure-8 compares the SNR for circular object and rectangular object.



**Figure-7: Composite Range equation of circular plate and circular cylindrical objects for different parameters ( $r = 0.125$  m,  $h = 1$  m,  $P_t = 1.5$  MWatt,  $f = 8$  GHz,  $G = 45$  dB,  $F = 3$  dB,  $B = 5$  MHz,  $T_e = 290$  K,  $L = 6$  dB,  $R = 20$  km  $\sim$  180 km.)**



**Figure-8: Composite Range equation of circular plate and rectangular flat plate objects for different parameters ( $r = 0.125$  m,  $a = 10.16$  cm,  $b = 5.8$  cm,  $P_t = 1.5$  Mwatt,  $f = 8$  GHz,  $G = 45$  dB,  $F = 3$  dB,  $B = 5$  MHz,  $T_e = 290$  K,  $L = 6$  dB,  $R = 20$  km  $\sim$  180 km).**

## 8.0 CONCLUSIONS

We have analyzed the approximate equation of the RCSs and the SNR performance variations. Our evaluations have confirmed that the approximate analysis method is applicable to a variety of different objects. It is revealed that change in the shape of the target causes huge change in SNR performance. That means at a fixed range large RCS provides better SNR performance. The further directions of this study can be to evaluate a compensation process to reduce the impact of the target geometry variation which causes SNR variation over same range.

## 9.0 References

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